SR-2005

USING FOLIAR FUNGICIDES TO MANAGE SOYBEAN RUST

LAND GRANT UNIVERSITIES COOPERATING NC-504

USDA

THE OHIO STATE UNIVERSITY
EXTENSION
OARDC

South Dakota State University
SDSU

UK COOPERATIVE EXTENSION SERVICE
University of Kentucky – College of Agriculture

Edited by

Anne E. Dorrance
Associate Professor and Extension Specialist
Department of Plant Pathology
Ohio Agricultural Research and Development Center
The Ohio State University

Martin A. Draper
Associate Professor and Extension Specialist
Plant Sciences Department
South Dakota State University

Donald E. Hershman
Professor and Extension Specialist
Department of Plant Pathology
University of Kentucky

Acknowledgments

Support for this endeavor was supplied to AED and NC-504 through USDA CSREES Smith-Level Special Needs Funds.

Special thank you to OSU Extension Director Keith Smith and OARDC Director Steven Slack for their support in this endeavor.

Additional copies available from:

Media Distribution
Communications and Technology
The Ohio State University
385 Kottman Hall
2021 Coffey Road
Columbus, OH 43210-1044
Phone: (614) 292-1607
Fax: (614) 292-1248
E-mail: pubs@ag.osu.edu

Trade Names

Trade names, suppliers, or other private labels are used for identification. No product endorsement is implied nor is discrimination intended toward similar products or materials not mentioned or listed. Ohio State University Extension and the participating universities and the Ontario Ministry of Agriculture, Food and Rural Affairs make no warranty or guidance of any kind, expressed or implied, concerning the use of these products.

Trade and manufacturers' names are necessary to report factually on available data; however, the USDA neither guarantees nor warrants the standard of the product, and the use of the name by USDA implies no approval of the product to the exclusion of others that may also be suitable.

Prepared By:

THE OHIO STATE UNIVERSITY
Jim Beuerlein, Dept. of Horticulture and Crop Science
Dennis Mills, Anne Dorrance,
Mike Ellis, Patrick Lipps, Dept. of Plant Pathology
Erdal Ozkan, Dept. of Food, Agricultural, and Biological Engineering

UNIVERSITY OF ILLINOIS
Scott Bretthauer, Agricultural and Biological Engineering
Dean Malvick, Dept. of Crop Sciences
Monte Miles, Glen Hartman, USDA-ARS

UNIVERSITY OF ARKANSAS
John Rupe, Rick Cartwright, Dept. of Plant Pathology
Dennis Gardisser, Biological and Agricultural Engineering

MISSISSIPPI STATE UNIVERSITY
Alan Blaine, Gabe Sciumbato, Billy Moore, Alan Henn, Dan Poston
Dept. of Entomology and Plant Pathology

IOWA STATE UNIVERSITY
Alison Robertson, X. B. Yang, Dept. of Plant Pathology
Palle Pederson, Dept. of Agronomy

UNIVERSITY OF MISSOURI
Laura Sweets, Dept. of Plant Pathology

PURDUE UNIVERSITY
Gregory Shaner, Dept. of Botany and Plant Pathology

UNIVERSITY OF NEBRASKA
Loren Giesler, Dept. of Plant Pathology

NORTH DAKOTA STATE UNIVERSITY
Carl Bradley, Dept. of Plant Pathology

THE PENNSYLVANIA STATE UNIVERSITY
Erick DeWolf, Dept. of Plant Pathology

UNIVERSITY OF KENTUCKY
Donald Hershman, Dept. of Plant Pathology

SOUTH DAKOTA STATE UNIVERSITY
Martin A. Draper, Plant Science Dept.

USDA/ARS
Alemu Mengistu, Crop Genetics and Production Research Unit

LOUISIANA STATE UNIVERSITY
Raymond Schneider, Dept. of Plant Pathology and Crop Physiology
G. Boyd Padgett, Northeast Research Station

UNIVERSITY OF MINNESOTA
Jim Kurle, Dept. of Plant Pathology

MICHIGAN STATE UNIVERSITY
Gene Safir, Dept. of Plant Pathology

UNIVERSITY OF WISCONSIN
Craig Grau, Dept. of Plant Pathology

VIRGINIA POLYTECHNIC INSTITUTE AND STATE UNIVERSITY
Erik Stromberg, Dept. of Plant Pathology, Physiology and Weed Science

ONTARIO MINISTRY OF AGRICULTURE AND FOOD
Albert Tenuta, Crop Technology

CORNELL UNIVERSITY
Gary Bergstrom, Department of Plant Pathology

UNIVERSITY OF DELAWARE
Bob Mulrooney
Dept. of Plant and Soil Sciences

KANSAS STATE UNIVERSITY
Doug Jardine, Dept. of Plant Pathology

UNIVERSITY OF MARYLAND
Arvydas Grybauskas, Dept. of Natural Resource Science and Landscape Architecture

UNIVERSITY OF TENNESSEE
Melvin A. Newman, Dept. of Entomology and Plant Pathology

TABLE OF CONTENTS

FROM THE EDITORS

Anne Dorrance
Martin Draper
Don Hershman

What an interesting time it is to be a soybean pathologist and to work on this fungicide manual. We should have had some inkling of what we were in for when we first met, last November 10, 2004, to begin the first draft. This was the same day that USDA Secretary of Agriculture, Ann Venneman, announced that Asian soybean rust had been found in the United States. A special feature of this first edition of the Soybean Fungicide Manual is the description of this first find by Dr. Ray Schneider, Louisiana State University. Soybean rust, more specifically, the fungus *Phakopsora pachyrhizi*, is a relatively new pathogen in the western hemisphere. This fungus arrived in 2001 in South America and has quickly spread to reach the southern shores of the United States by 2004. Fungicide companies and USDA research have primarily focused on which compounds have efficacy—they have not necessarily looked at what is the best timing of application on soybeans for each of these fungicides, nor has any work been completed on the economics and cost returns. Much more research is needed which focuses on the best timing, length of fungicidal activity, and which combinations of treatments are the most cost-effective. In addition, will U.S. soybeans which have indeterminant growth habits match the results from other regions where determinants are grown? More research is in progress in South America as we compile this first edition. Many of these studies in the 2004–2005 production season in South America are now focused on some of these questions. This will be a great benefit to us for making recommendations this next summer in the United States and Canada. As more and more data becomes available, these fungicide guidelines will continue to change. Changes will be made to the website **http://www.oardc.ohio-state.edu/SoyRust/** where this publication will be posted, so please check this location or your state/government Extension website to get the most current information on managing soybean rust. This is a "new" pathogen; despite

More research is in progress in South America as we compile this first edition

this, we have learned a lot, but there are still many questions.

This manual covers some basic information about the biology of soybean rust, fungicides, and an appendix with many tables for some background information. In addition, we have provided information on fungicide guidelines, as well as fungicide application techniques. Although fungicide application techniques in North America are advanced, these can be improved to optimize efficacy and economic return.

One final precaution on fungicide resistance. Two main chemistries available for management of soybean rust, the strobilurins and triazoles, both have single-site modes of action. Several other fungi have developed resistance to these materials previously. No one really knows how or if rust fungi can also develop fungicide resistance. But since we have so few compounds and fungicides offer the only means of managing soybean rust for the foreseeable future—it is critical that we follow the guidelines put in place to delay or minimize this happening.

We all have experience of working with other fungal pathogens which can devastate other crops, but are manageable. We do not want to give a false sense of security—proper fungicide timing will be key to managing soybean rust and maintaining profitability for the coming years. It will be key in these first few years that we continue to learn more about this pathogen and build up knowledge of how to properly use fungicides for soybean rust management.

We hope that this manual will serve as a good reference for all of your questions on soybean rust. We welcome your comments for improvements. Our wish is still for a "rust-free" season.

4 FIRST FINDING OF SOYBEAN RUST

Raymond W. Schneider
Louisiana State University

Soybean rust was first discovered at an LSU AgCenter research farm in Baton Rouge on November 6, 2004. This was not a research plot, as had been reported in the popular press. Rather, it was about a 5-acre production field being grown in support of research farm operations. The field was planted in mid-July to a maturity group VII variety.

An Illinois soybean farmer and his wife were visiting me on November 5, and I offered to show them some diseases with which they were not familiar. As we walked through several experimental plots and the production field looking at frogeye, Cercospora leaf blight, stink bug damage, and delayed maturity; I began to notice unusual symptoms on occasional leaves.

Figure 1. R. W. Schneider (left), O. Perez-Hernandez (right), and X. B. Yang (back) examining volunteer soybean plants in a sugarcane field in Iberia Parish, Louisiana. Photo credit: M. Claesgen, LSU AgCenter.

These symptoms were difficult to discern because of the presence of frogeye and the late stage of crop development (R6). The new symptom occurred on leaves that had not yet begun to senesce, including very young leaves that had only recently expanded deep within the canopy. I finally stopped to look at some of these leaves with a hand lens. My visitors, who noticed that I was particularly interested in these leaves, asked if this was something new. In fact, they asked if this could be rust. I had previously seen pustules with urediniospores and replied that it may be but that it would have to be confirmed.

I was fairly certain that I had been looking at soybean rust, so once my guests left, I called Dr. Clayton Hollier, Extension pathologist, who was our lead person for the Louisiana Rust Response and Action Plan. Dr. Hollier and I spent Saturday evening looking at spore preparations and taking many photographs. We then decided to activate the action plan. Monday morning, November 8, according to the plan, we sent specimens via overnight mail to Dr. Mary Palm of the USDA/APHIS lab in Beltsville, Maryland, where our diagnosis was to be confirmed by DNA analysis. We spent Tuesday afternoon and evening waiting anxiously for the results. Dr. Palm called us that evening to let us know they were going to repeat their tests, so we went home Tuesday night not knowing the results of the DNA analysis. On Wednesday morning

we received confirmation that we, indeed, had found the first natural occurrence of soybean rust in the United States.

The confirmation prompted activation of the national Soybean Rust Assessment Team, which was composed of individuals who had experience with the disease in other countries. Team members were Arnold T. Tschantz, X. B. Yang, Monte R. Miles, Reid D. Frederick, Morris R. Bonde, Glen L. Hartman, Russ Bullock, and Anwar Rizvi (Figure 2). By Wednesday evening, a "unified command" was established and provided with an office in the LSU Department of Plant Pathology and Crop Physiology, complete with a bank of computers. Also, a large conference room was converted into a "situation room," and two labs were outfitted with several dissecting scopes and compound microscopes.

On Wednesday, November 10, our soybean extension pathologist, Dr. Ken Whitam, contacted county agents throughout the state and asked them to find soybean fields that had not yet been harvested, fields that might find volunteer soybean plants, and stands of

Figure 2. Members of the national Soybean Rust Assessment Team.

kudzu. He then mapped out survey routes for four teams that would spend all day Thursday, November 11, surveying most of the soybean production areas in south and central Louisiana (about 10,000 square miles). The teams were composed of a local pathologist or other professional who was knowledgeable in soybean diseases and at least one experienced member of the rust assessment team. As each team entered a new parish (county), it was met by a county agent who had already located sites to be surveyed. Suspected positive samples were returned to the department, and the entire survey group spent Thursday night examining specimens and preparing them for overnight shipment to the APHIS lab in Beltsville for confirmation (Figure 3). In total, 64 sites in 15 parishes yielded 56 samples, including nine from kudzu. Of the nine kudzu samples submitted for confirmation, six were confirmed as positive.

Figure 3. Examining soybean specimens during the night of November 11, 2004, after returning from an extensive survey in Louisiana.

Our experiences in Louisiana may be instructive for others during the 2005 season. Symptoms were not found on volunteer soybean plants during the survey of November 11, even though some volunteers were beginning to flower. However, infected volunteers were found during a subsequent survey conducted on December 6. Of particular concern was our observation of rust on unifoliolate leaves of plants still in early vegetative development (Figure 4).

There are several lessons to be learned from our observations. The probability of finding rust is increased if surveys are conducted beginning about a week after a rainy period. Also, one must examine leaves of different ages on the same plant because each leaf will have a different environmental history. In the case of the infected unifoliolate leaves, symptoms would likely have been missed entirely if the second survey had been conducted a few days later. This is because the infected leaves would have abscised by then, and new leaves would be free of symptoms. The take home message is that frequent and attentive scouting will be required

for rust to be found at its earliest stages in 2005.

Rust symptoms were readily discernable with a 14X hand lens when leaves were free of other diseases. However, when leaf samples were collected after more than about a week of dry weather, only a small fraction of the pustules produced urediniospores, even after incubation in a moist chamber.

Rust lesions were easily overlooked when other foliar diseases were present. Cercospora leaf blight, for example, appeared to inhibit the development of rust symptoms even when leaf blight occupied a small portion of the leaf. Under these conditions, rust pustules remained small, almost pinpoint in size, but retained their distinctive color. These pinpoint lesions often formed in clusters, and were most apparent on the upper leaf surfaces, although urediniospores were produced on the lower leaf surfaces. Frogeye did not seem to have this effect, and it was common to find well-advanced rust lesions scattered among frogeye lesions. It appeared that older rust infections killed entire sections of individual leaves, but uredinia were clearly visible with a hand lens. Otherwise, these symptoms could easily be confused with brown spot, Alternaria leaf spot, or aerial blight caused by *Rhizoctonia solani*.

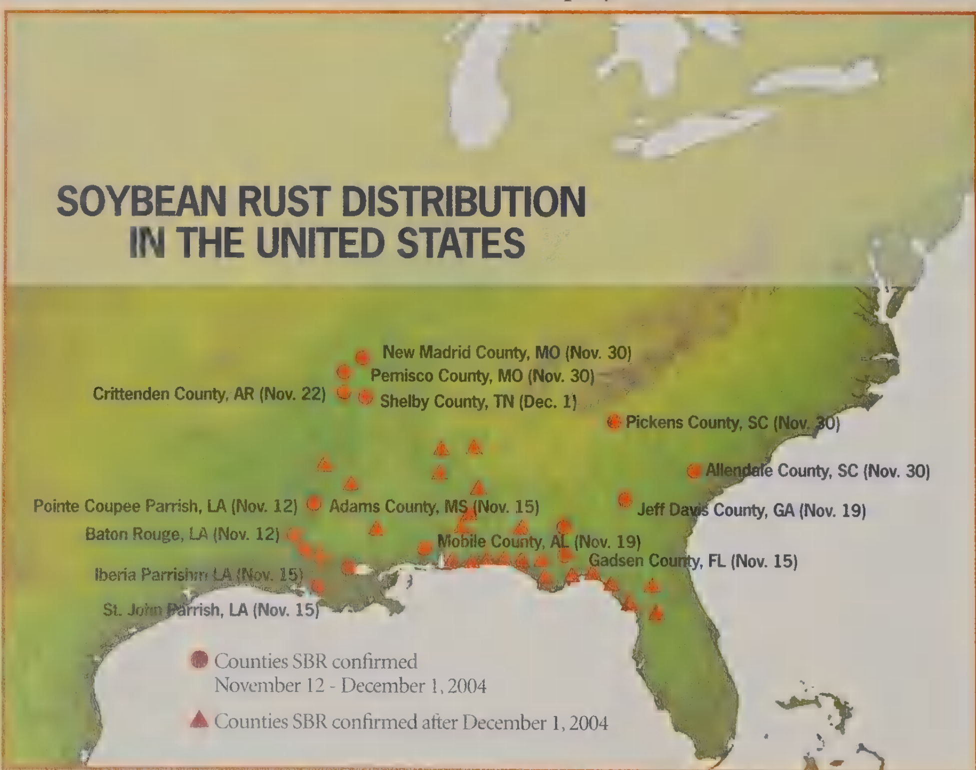
Even though our experience with soybean rust in the United States is very limited, we were fortunate that it was found late in the 2004 season, after the U.S. harvest was 99% complete. My hope is that the above notes on field observations and accompanying images may enhance our early detection capability in 2005.

Figure 4. Volunteer soybean seedling with rust symptoms on unifoliolate leaves. Note absence of symptoms on first trifoliolate. It is probable that younger leaves had not been exposed to conducive environmental conditions.

Anne Dorrance, Donald Hershman, and Martin Draper
The Ohio State University, University of Kentucky, and South Dakota State University

Economic importance of Asian soybean rust

Asian soybean rust, a disease that causes serious crop losses in many parts of the world, was first detected in the Continental United States in November 2004. Soybean rust is caused by the fungus *Phakopsora pachyrhizi*. Long known to occur in Asia, the fungus spread to Zimbabwe, South Africa, Paraguay, Brazil, Colombia, and now the United States during the last 10 years. Yield losses in other parts of the world due to soybean rust have been reported to range from 10 to 90%. Annual yield losses for North American soybean production are predicted to be at least 10% in the upper Midwest, Northeast, and Canada, and 50% or greater in the Mississippi Delta and southeastern states. However, losses in hard-hit areas anywhere in North America could exceed 80% if effective management tactics are not deployed.



SOYBEAN RUST DISTRIBUTION IN THE UNITED STATES

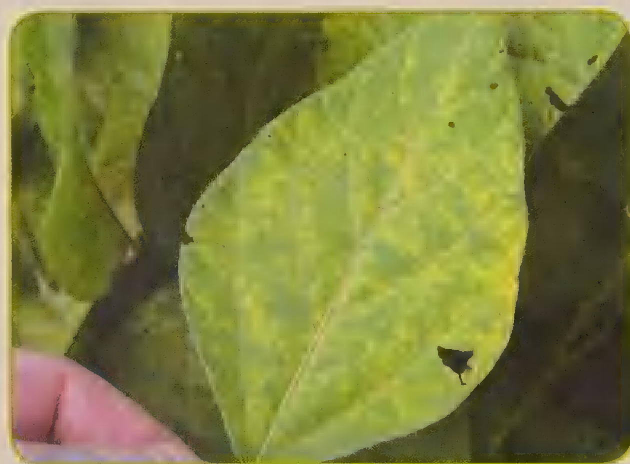
Soybean rust disease symptoms

The first symptoms of soybean rust are small brown or brick-red spots on the upper leaf surface. The spots, which are initially less than half the size of a leaf hair, are frequently best seen by holding leaves up to a light source so that they are backlit. Eventually pustules will form in the spots, primarily on the undersides of leaves. Pustules initially have raised centers that eventually break open (circular opening) to reveal masses of urediniospores. Spore masses can readily be seen using a 20x hand lens. As pustules become numerous, leaves turn yellow and drop prematurely. Prematurely defoliated plants have fewer pods, fewer seeds per pod, and poorly filled seeds. Be aware that soybean rust looks very similar to many other soybean foliar diseases in the early stages of infection, including brown spot, bacterial blight, bacterial pustule, Cercospora leaf blight, downy mildew, and frogeye leaf spot.

Upper leaf symptoms

Pustules (spores) under 20x hand lens

Backlit leaf



Top leaf—mid-stage of infection

Bottom of leaf with severe infection

Top of severely infected leaf

Soybean rust disease cycle

Spots and pustules form in leaves when fungal spores, called urediniospores, blow into fields, land on soybean leaves, and infect leaves under favorable conditions. Spots are evident about 4 days after infection and pustules can be seen after about 10 days. One pustule can produce urediniospores for about 3 weeks. Wind disperses these spores, which in turn result in more infections. Rapid increases in disease incidence and severity usually coincide with canopy closure and the beginning of crop flowering. This cycle of infection and pustule/urediniospore development will continue until the plant is totally defoliated or until environmental conditions no longer favor disease development. The maximum disease severity that a leaf can support before defoliation occurs may be as little as 30 to 40% of the total leaf area affected by soybean rust. Premature defoliation can occur in 4 to 6 weeks from initial infection.

Soybean rust, like most rusts, is capable of progressing rapidly once initial infection takes place. Rusts produce spores that reinfect the host plant population in a field, leading to very rapid increase in disease under favorable conditions. Soybean rust progresses rapidly when dew periods are long (and frequent) and/or rain events are frequent, and when temperatures are optimum for infection (Table 1). ***Note: infections can occur over a broad range (59–84˚F), but will take a longer period of time at temperature extremes.*** The most favorable period for soybean rust is likely to vary for different parts of the country, but risk may be greatest, nationwide, in July.

As seen in Table 1, there are overlapping environmental criteria for infection for wheat, corn, and soybean rusts. Although soybean rust takes slightly longer to complete an infection cycle than the other two rusts, the potential for soybean rust to cause widespread damage is greater. This is due to uniformly high susceptibility of current soybean cultivars compared to wheat and corn, and a larger number of host plants from which infectious spores can be produced.

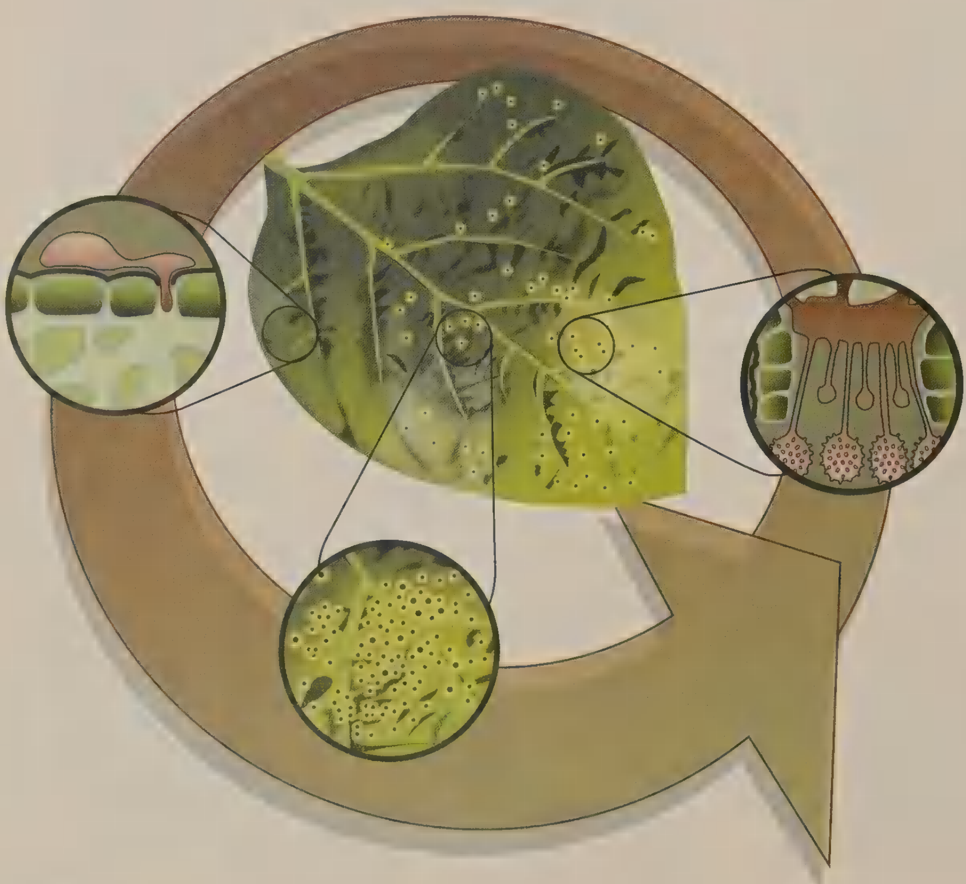


Figure 5. The simple disease cycle of soybean rust. At this time, only one spore stage (urediniospore) is known to infect soybeans. It is blown into the crop with prevailing winds.

Rust	Infection Optimum	Time needed for Infection (hrs)	Generation Time (days)
Wheat leaf	59–73°F	6–8	7–10
Corn (common)	61–77°F	6	7
Soybean	68–77°F	6	9–10

Table 1. Infection optimum temperatures and generation times for soybean rust as compared to two other common rusts.

Because of the way successive infections develop with rust fungi, they are referred to as "compound interest" diseases. Just as money invested at compounded interest increases exponentially, the number of rust pustules in a field increases in a compound manner. The difference is that your bank account may earn 3–5%, or a good mutual fund may earn 12% per year; however, rust may increase at a 300% rate compounded every 9–10 days as in the case of soybean rust (Figure 6)!

Fungicides provide protection and delay soybean rust epidemics as long as they remain in sufficient concentration in or on the soybean leaf. For fungicides to be optimally effective against soybean rust, they must be applied at the proper time. Experience from Africa and Brazil indicates that early treatment is critical for optimum fungicide performance with soybean rust.

Annual survival and movement of *P. pachyrhizi*.

The soybean rust fungus is an obligate parasite and cannot survive outside host tissue except as short-lived urediniospores. As a result, this fungus will only overwinter in southern areas that are free from killing frost (Figure 7). In any given year, initial infection will depend upon: 1) where the soybean rust fungus overwinters, 2) where environmental conditions

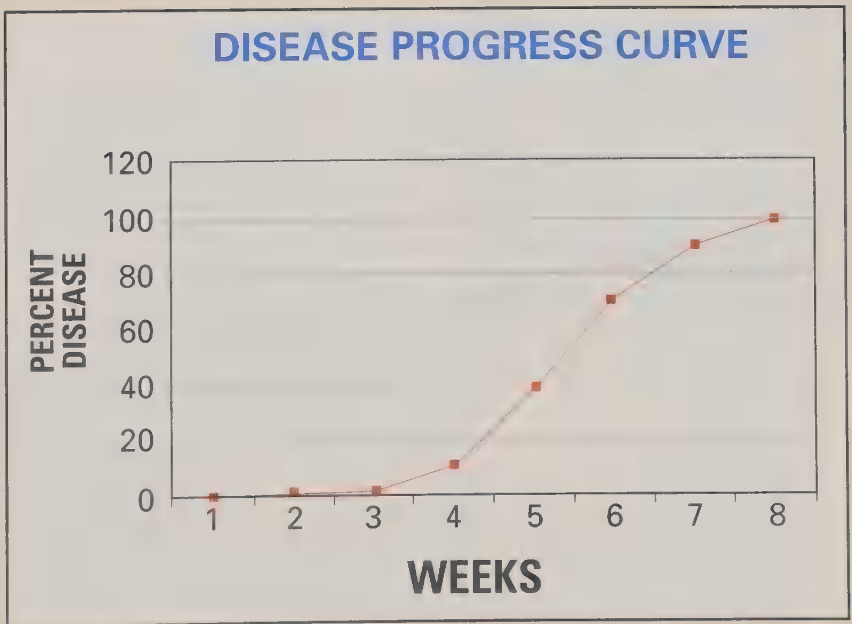


Figure 6. A typical rust disease progress curve. Since rusts produce more spores capable of reinfecting the host plant disease severity starts slowly, but increases logarithmically until the food source, leaves, becomes limiting or the environment becomes less favorable for growth and reproduction.

Fungicides are critical in a soybean rust disease management program. However, several important soybean diseases are not effectively controlled with foliar fungicides. These include soybean cyst nematode, Phytophthora root and stem rot, and all of the bacterial and viral diseases. Additionally, foliar fungicide are not equally effective against many common diseases, including brown spot, Cercospora leaf blight, frogeye leaf spot, Sclerotinia white mold, and Rhizoctonia aerial web blight, among others.

favor infection, and 3) the existence of sufficient tracts of winds and storms to move spores out of overwintering locations and into new regions.

Management overview

As in other countries where soybean rust occurs, fungicides will be the primary means of managing soybean rust in the United States and Canada until acceptable resistant cultivars are developed. As soybean rust has spread around the world, fungicide use has become commonplace. Although the disease can cause significant losses in yield and quality, producers in other parts of the world have learned to economically manage soybean rust through the use of fungicides. Depending on the location in the world and the economics of production in those areas, various fungicide products are used. The economic return on those products varies based on disease pressure, crop yield potential, and efficacy of available products. Nevertheless, fungicides have produced acceptable control of soybean rust when properly used.

Despite the significant benefits, controlling soybean rust with fungicides comes with a cost. For example, soybean producers in Brazil spent close to $1 billion on fungicide control of soybean rust during 2003–2004. In addition, some Brazilian producers have reported difficulties in deploying appropriate fungicide treatments when needed. Difficulties include fungicide availability, early detection of initial soybean rust symptoms, inability to spray total acres as quickly as needed, application errors, physical barriers to application, and relative high cost of treatment. U.S. soybean producers are likely to encounter similar problems. Costs of applying fungicide for soybean rust control are estimated to range from $10 to $35 per acre per application.

Early detection of soybean rust is key to successful management of the disease. Fungicides must be applied in the early stages of a soybean rust epidemic (i.e., pre-infection to ≤ 5% incidence on leaves in the lower canopy) to be highly effective. Disease control may be severely compromised if applications are made after soybean rust is firmly established (>10% incidence in the mid-canopy) or before any infections occur in a field. Making applications even later in a disease epidemic may be an exercise in futility. Reports from Brazil indicate that when 20 to 30% of the soybean leaves in the mid canopy are affected by soybean rust, fungicides are no longer able to protect plants sufficiently from additional infections, or yield reduction is already so great that a fungicide application cannot recover treatment cost.

Generally speaking, 10% disease incidence in the lower canopy should be considered the **maximum action threshold** for initial application of fungicides for soybean rust management using a curative strategy. This amount of disease is very small and will

require thorough scouting in the field. A note of caution is more disease is often present than can be detected using traditional field scouting methods. This is because some infections will be in the pre-symptomatic stages when observations are made.

Data from Africa and South America indicate that not all fungicides have equal efficacy against soybean rust. Also, some fungicides may cause phytotoxicity on certain soybean cultivars, under some conditions. Research is needed on fungicide efficacy under North American conditions, and to determine which cultivars may be injured by which chemistries, and which combinations result in measurable yield loss. Thus, the decision as to which fungicide to apply can have a great influence on the outcome. Because of the differences in efficacy and activity, it is critical for producers to have access to products with multiple modes of action, which provide for effective disease control, but also minimize the chance of resistance development to these fungicides.

Preliminary epidemiological models indicate that soybean rust may not be an economic problem in every production year in every region of the United States and Canada. The soybean rust pathogen may, in fact, behave very similarly to the wheat or corn rust pathogens where the timing of rust movement from overwintering locations to the main production regions varies from year to year. This will make monitoring and forecasting programs all that more important to both limit unnecessary fungicide use and facilitate effective deployment of fungicides.

Although fungicides are an important soybean rust management tool, it should be noted that only a few fungicides currently have a federal label for use on soybean in the United States and Canada. Registrations and recommendations will change over time as more products move through the registration process, and as we become more familiar with the level of control provided by each of these products. The following comments are intended to provide general information about currently registered fungicides. It is always the applicator's responsibility to read and follow all label instructions. In today's modern agriculture, regulations and recommendations can change rapidly; therefore, check with your local agricultural supply dealer, or the pesticide manufacturer, for updated label information prior to making applications.

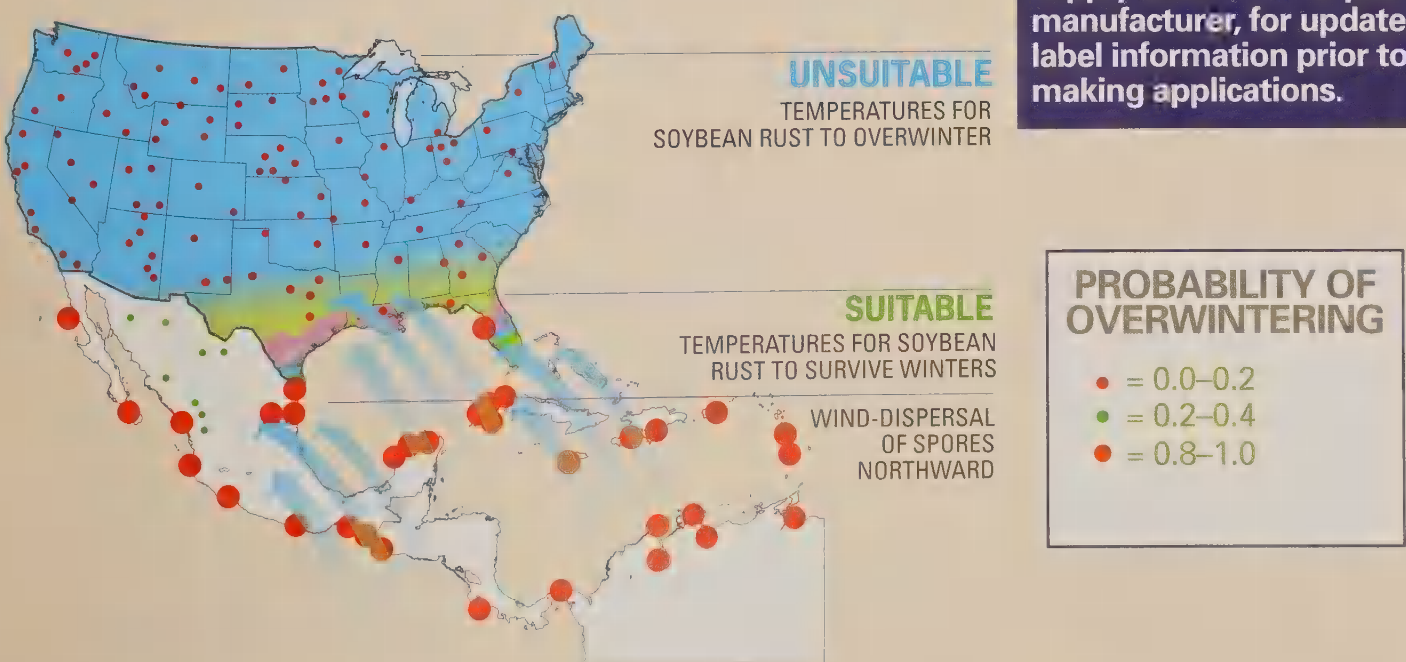


Figure 7. Potential sites in North America, Caribbean, Central America, and South America where soybean rust may overwinter. (Yang et al., 2004)

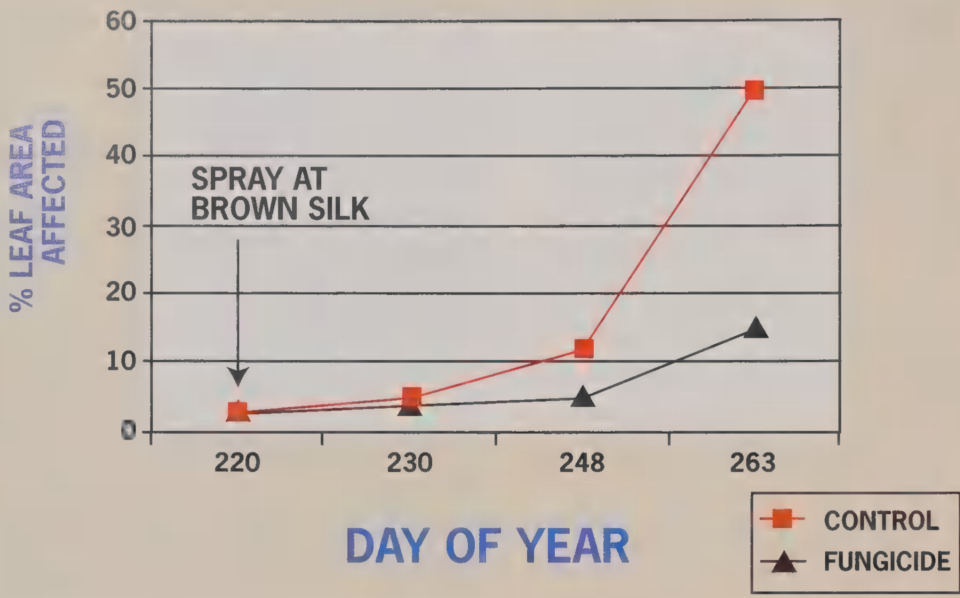


Figure 8. Fungicide applications alone may delay, but not completely eliminate a disease epidemic. This example is of common corn rust. Soybean rust may behave similarly in some parts of the North America. (Lipps et al., unpublished)

Importance of applying fungicides correctly

Fungicides must be applied correctly to achieve effective, economical control of soybean rust. Because soybean rust tends to initially develop in the lower and mid canopy, thorough coverage of foliage, including penetration of spray into the canopy, is essential to achieving a successful soybean rust spray program. Fungicides are best applied at higher gallons per acre, higher pressures, and with different nozzles than herbicides. Research is under way to improve fungicide spray technology for best management of soybean rust. Results from these studies may also help with future delivery of insecticides to soybean. The most important thing to remember about soybean rust control with fungicides is coverage. Control is directly related to how thoroughly the fungicide spray covers leaf tissue. Better coverage results when the spray is delivered as fine to medium droplets (about 200–300 µm). This is why higher spray pressures, nozzles with smaller orifices, and higher spray volumes per acre are used with fungicides than is customary for herbicides.

Despite the considerable need to improve existing fungicide spray technology, current spray technology (aerial and ground) has performed adequately for soybean rust control in other countries. Similarly, North American soybean producers have access to the appropriate spray technology to achieve excellent results against soybean rust using foliar fungicides. One question that is still to be answered, however, is if North American soybean producers have the capacity to spray fields as quickly as may be needed during a soybean rust epidemic. This could be a special challenge in areas of the country that have historically relied on custom applicators to apply pesticides.

Recent fungicide special labeling activities

The normal route of pesticide registration in the United States is through Section 3 of the Federal Insecticide, Fungicide and Rodenticide Act of 1947 (FIFRA). This Act has been amended several times (most extensively in 1972), but it remains the foundation for pesticide regulation. Registration of all pesticides is handled by the United States Environmental Protection Agency (EPA). Section 3 of FIFRA provides the normal

pesticide registration process. However, the EPA acknowledges that there are needs for exceptions to the general process. As such, sections are provided in the law that allow for rapid response to critical issues, thus giving states a legal avenue to address special local needs (Section 24c exemptions) or emergency/crisis situations (Section 18 exemption). Thus, producers may have access to products made available that are not specifically labeled for a given crop or pest, but have been shown to effectively control the pest in question. For differences contact your state or provincial Department of Agriculture.

In response to the recognition that soybean rust could become a serious problem in North America, and that there was an inadequate supply of labeled, efficacious fungicides, a Section 18 template was developed in the winter of 2003 to facilitate submission of Section 18 applications to EPA from each soybean-producing state. Several products were proposed based on the best available information, from among products that had been evaluated against soybean rust in other countries. Over the coming years, the preferred products will likely change as more data are generated in the United States. Each state must request the Section 18 products from EPA for them to be legally available for use by growers in that state.

In Canada, a similar need for efficacious fungicides resulted in an Emergency Use Submission to the Pest Management Regulatory Agency (PMRA) in 2004. More products will be submitted to PMRA in the future. As well, a full Canadian registration of these products will be pursued for soybean rust control.

Purpose of publication

Foliar applications of fungicides to the soybean canopy will be the standard disease management practice to limit yield losses due to soybean rust for the foreseeable future. This bulletin reviews the factors involved in making fungicide spray decisions and basic fungicide information, including mode of action, application, and use strategies. Specific recommendations for each state, province, or region are likely to vary depending on whether sources of rust inoculum are within the region, state, or province; how conducive the weather is for soybean rust; the growth stage of soybean when rust becomes a threat; yield potential of crop; and price of soybeans. For these reasons, be sure to consult local soybean rust management guidelines and information when making decisions on best management practices for soybean rust control.

MAKING FUNGICIDE DECISIONS FOR MANAGING SOYBEAN RUST

X.B. Yang
and Alison Robertson
Iowa State University

Importance of risk assessment

Correct assessment of the risk of soybean rust is key to making effective and economical fungicide applications for soybean rust control. Like corn and wheat rusts, soybean rust is expected to spread from south to north during the growing season. Thus, it is possible to assess progressive risk of soybean rust over a growing season and use this information to make informed fungicide use decisions.

Data from the 1970 southern corn leaf blight epidemic may help to shed light on the potential spread of soybean rust in the United States and Canada. In fact, there is considerable overlap between the 1970 epidemic in corn and future soybean rust epidemics. Corn and soybean both grow in the same geographic areas and have similar growing seasons, and in 1970 there was little resistance in corn to southern leaf blight and there appears to be no resistance to soybean rust at the present time.

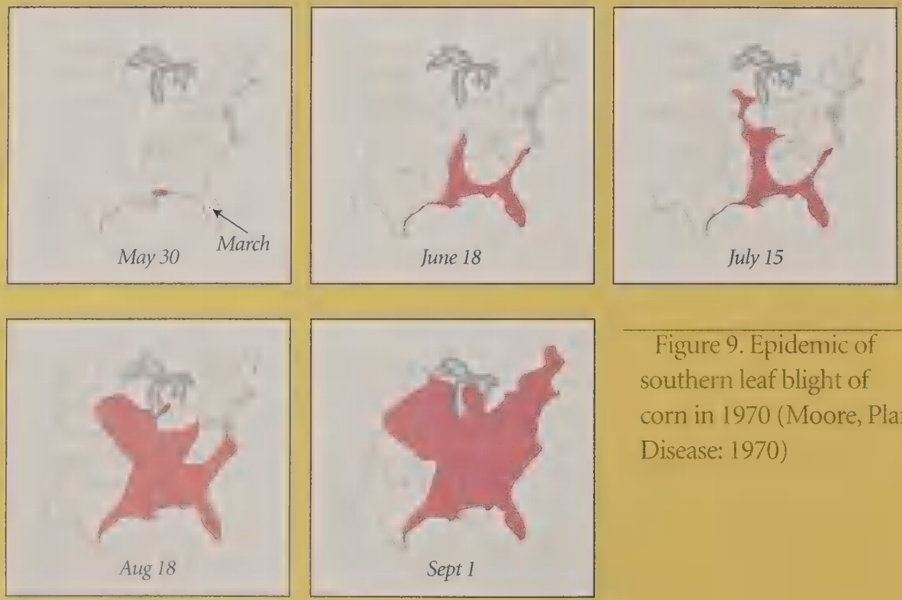


Figure 9. Epidemic of southern leaf blight of corn in 1970 (Moore, Plant Disease: 1970)

In the 1970 epidemic, the movement of disease was recorded during the season as shown in the five maps below. The red areas depict where southern corn leaf blight was found at each date. The disease outbreak was first noticed in March in Florida, and by May, 20 outbreaks were reported in Mississippi and Alabama coast areas (Figure 9). By July 15, the disease was found in Iowa, Illinois, and Minnesota. A month later, the affected area had increased substantially, and by September 1 virtually all corn east of the Rocky Mountains was affected.

There are three key factors in determining the risk of soybean rust movement into more northern soybean production regions: 1) the occurrence of soybean rust during the spring and early summer in the Gulf Coast area, which determines the amount of spores available to blow northward; 2) the July–August weather conditions that favor soybean rust development; and 3) northward movement of soybean rust spores in weather systems and by "green-bridging."

Producers in many soybean production areas in North America may be able to assess the risk of seasonal outbreaks using the following steps throughout the year:

******March*: Monitor information on the occurrence of soybean rust on host plants in Florida and southern Texas. This will be an early indication of the likelihood of rust spore movement into the Gulf Coast states.

**April, May, and June*: Monitor reports on soybean rust occurrence in Louisiana, Mississippi, and Alabama. These are potential regions that might act as a rust pathway to the north. Texas and Georgia are also states to watch, but have less predictive impact than the other three states. If outbreaks occur on soybean plants or kudzu in any of these states during this period, the spores are likely to reach northern soybean regions as early as July. A network of sentinel plots stretching from the Gulf Coast and into the upper Midwest and Canada will provide critical ground-truth information on the actual occurrence and progress of soybean rust in North America.

Factors to consider in determining risk

The decision to spray or not to spray fungicides for control of soybean rust is complex. Fungicides are highly effective at controlling soybean rust in Brazil, South Africa, and Zimbabwe, but North American conditions are quite different from those in Africa and South America. Consequently, U.S. and Canadian soybean producers **must** resist the temptation to base fungicide spray decisions solely on what is being done elsewhere. Of course, we should learn from the successes and the failures other countries have experienced in managing soybean rust with fungicides. In addition, to the extent possible, we should adapt existing recommendations to the diverse soybean production regions in the United States and Canada.

There are several factors to consider in making spray decisions to manage soybean rust. It is expected that although soybean rust will affect soybean production throughout North America, it will be endemic in some areas, and seasonal in others. Disease epidemics are also likely to vary from season to season. Thus, spray decisions (i.e., determining the need to spray, when to spray, and the number of sprays) will likely be different from region to region and season to season. Generally, fungicide programs should not be deployed for soybean rust management until the risk of infection is high.

The following criteria are the basis of soybean rust risk assessment.

1. Crop stage: Most data and experience from other parts of the world indicate that for soybean, the period from beginning flowering (R1) through full seed (R6) is the most critical for soybean rust management. In other words, if a crop is before beginning flowering or after full seed, fungicide sprays may not produce an economical return. However, there are limited data where fungicide applications made during the vegetative stages are occasionally economical. Efficacy data on fungicide use under North American conditions are needed to more clearly define the critical window of protection for soybean rust in the United States and Canada.

Nevertheless, the best information to date suggests that applications

Long-range weather predictions made in April and May, indicating that July and August weather conditions may favor rust outbreaks in the north, should be considered in risk assessment for soybean rust. However, it must be understood that predictive models are still under development and will need validation. Thus, the most reliable way to establish the need to spray fungicides for soybean rust control continues to be early disease detection.

Sentinel Monitoring

- What is it? Sentinel monitoring involves intensively observing a small plot of soybeans that have been planted at the earliest possible planting time. This could be a small area within an early planted field or an area of soybeans that are planted 2 to 3 weeks earlier than surrounding fields. Sentinel plots can be small (30 X 30 sq ft) or much larger, depending upon the needs and resources available. The more sentinel plots there are, the greater the likelihood that soybean rust will be detected when the disease first moves into an area.
- How are these useful? These plots are surveyed at least every week for the presence of soybean rust and more frequently during periods when conditions are favorable for disease development. Plants, especially lower leaves, are carefully examined for soybean rust lesions.
- Once rust is found, disease alerts are issued for the surrounding area and spray decisions are made.
- Observations from local sentinel plots may help soybean producers in neighboring and distant states to determine their soybean rust risk.

made before R1, or after R6, may not produce an economic result.

2. Output from soybean rust forecasting systems: Forecasting systems can be effective decision-making tools for managing soybean rust. These systems can be simple, with disease forecasts being based on observations from sentinel plots; or forecasts can be based on complex computer models, and current and predicted weather. Computer models have been developed for soybean rust forecasting, but they still need to be validated. Sentinel plots, on the other hand, have been used effectively in Zimbabwe and Brazil to indicate when fungicide application is necessary. Usually sentinel plots involve planting early-maturing soybean varieties about 3 weeks before the commercial crops are planted. Spray warnings are given once soybean rust is found in the sentinel plots. Since soybean rust is usually first observed on plants of more advanced growth (beginning flowering [R1] or later), the sentinel plantings often provide an opportunity to observe the first signs of the disease BEFORE the disease gets a foothold in neighboring production fields. Scouting results from more distant sentinel plots may also be very useful. For example, sentinel plot data from the Southeast and Mid-South may be very useful to soybean producers in the Midwest, Northeast, and Canada who are attempting to establish their soybean rust risk.

3. Results of scouting, detection, and diagnostic activities: Before deciding to apply a fungicide for soybean rust control, it is necessary to determine if soybean rust is present and at what level. This can only be accomplished through field scouting and accurate disease diagnosis. Scout carefully—a thorough visual examination of soybean plants in fields, over time, is crucial. When walking through fields, periodically stop and closely examine the soybean plants. Look down into the lower plant canopy because this is where initial soybean rust pustules usually first develop. Closely examine the undersides of leaves for "tell-tale" pustules of soybean rust. Be sure to examine several sites throughout each field; do not restrict scouting activities to the edges of fields.

Rust fungi, in general, require free moisture and/or high humidity to germinate and infect leaves. Thus, when scouting fields, focus on areas where moisture collects, such as low spots, or areas of poor air circulation. If there are places in a field with a distinct yellowing or browning, these areas should be targeted in addition to the standard scouting pattern being used. If soybean rust is suspected, collect samples and carry or "overnight" them to your state's plant disease diagnostic laboratory. Alternatively, report the location to your local Extension office immediately. The earlier an infestation of rust is detected, the more effective carefully timed fungicide applications will be.

Be aware that several other foliar diseases are easily confused with soybean rust, especially when rust is in the early stages of pustule formation (***see "Similar Diseases" section in this book, p. 39***).

Single vs. multiple fungicide applications: The number of fungicide sprays required to achieve acceptable control of soybean rust will depend on three main factors: (1) the stage of crop development when the disease first appears, (2) the incidence and severity of infection as determined by crop scouting, and (3) current and forecasted weather conditions.

The earlier in the growing season soybean rust is detected, the more sprays may be needed to achieve acceptable disease control. Three applications may be needed if the first application is made at or before beginning flowering (R1), and the weather continues to favor rust development. This scenario frequently plays out in Zimbabwe where the first application is usually made at first flowering, followed by two more applications at 21-day intervals. In dryer parts of Brazil and Paraguay, disease frequently moves in mid- to late-season, or the weather turns dry after initially favoring soybean rust. In these situations two or even a single fungicide application may provide acceptable results. If growing conditions are hot and dry, soybean rust may never develop to damaging levels and fungicide applications may not be needed at all.

Each of the above scenarios, and many others, may occur in North America over the next several years. Our experience is likely to be highly variable, considering the range of conditions under which soybeans are produced in the United States and Canada. To avoid mistakes and possible crop failures, producers should discuss spray options with someone who is familiar with local farm operations, but also has familiarity with soybean rust biology and the range of fungicide

SCOUTING - FIELDS

- *Begin at the appearance of first true leaves*
- *Sample 1–2 times a week, through full pod stage*
- *Observe multiple sites per field*
- *At each site, observe 100 leaves per canopy level (top-middle-bottom)*
- *Requires patience and time in the sampling*
- *More intensive scouting 10–14 days after a rain event may increase your ability for detection*

Some U.S. soybean producers routinely irrigate crops during dry periods in order to maintain crop yield potential. These producers must be aware that irrigation is likely to have a significant impact on soybean rust if spores of the pathogen have blown into a field. Fungicide use decisions are also likely to be impacted by irrigation decisions.

control options. Be aware that what works in Brazil or Zimbabwe may not work well in any or all regions of North America.

4. Timing of fungicide applications: When it comes to timing of application, there are two obvious mistakes, both of which can be very costly. Soybean rust can spread very quickly and poor timing of fungicide sprays will significantly increase the risk of disease control failure. Spraying too early can result in the fungicide wearing off by the time infection occurs. Conversely, waiting too long to spray can result in the disease progressing beyond the point where effective control is possible.

The ideal time to make the first fungicide application for soybean rust control is when the risk of infection is high, but before infection occurs; this is the purpose of sentinel plots. A coordinated network of sentinel plots, stretching from the Gulf Coast and into the upper Midwest and Canada, would be of considerable value in facilitating appropriate spray decisions for soybean rust control. Early detection of soybean rust will also be accomplished by various disease monitoring programs, including the National Plant Diagnostic Network and state and Canadian provincial plant disease clinics. In addition, growers should keep tabs on soybean rust information coming from regions to the south of their state to determine where the disease is developing and to what extent (refer to www.sbrusa.net).

A word of caution: Each fungicide has a unique preharvest interval indicated on the product label. If a fungicide spray is needed for soybean rust control late in the season, this preharvest interval, which varies from as short as 14 days to as long as 42 days (Table 2), may have a great impact on which fungicide you may legally apply. To avoid problems, it is prudent to ascertain a product's preharvest interval **BEFORE** making an application.

FUNGICIDE CLASS	PRODUCT	PREHARVEST INTERVAL
Chloronitrile	Bravo, Echo	42
Strobilurins	Quadris**	14
	Headline**	21
Triazoles	Domark	21
	Folicur**	30
	Bumper Laredo Propimax Tilt**	28
Strobilurin & Triazole	Stratego Quilt*	30
	Headline SBR	21

Table 2. Preharvest intervals for soybean rust fungicides

* Section 18s still pending (March 29, 2005)

** Canadian Emergency Use (March 11, 2005)

5. Information reliability: We are exposed to information from a wide range

of sources—from the corner coffee shop, to the internet, to publications and newscasts. It is important that growers base fungicide spray decisions on information from reputable sources and proven facts. These include university Cooperative Extension, government, industry or commodity group web sites, and newsletters or news releases from these organizations.

6. Understanding risks associated with fungicide spray decisions: It is imperative that growers follow spray guidelines and adhere to the labeled rates for each fungicide. As previously mentioned, the method of fungicide application is very important—fungicides must cover the whole plant and get into the canopy to be optimally effective. If the correct equipment (nozzle type, pressure, adjuvants, and timing) is not used, there is considerable risk of failure. Failure to adequately control soybean rust will also occur when poor fungicide decisions are acted on, or when otherwise good decisions are not implemented properly. Either situation is likely to result in reduced economic returns. Spray decisions may also have an affect on crop insurance claims filed. Therefore, it is essential to keep excellent records of what was done and how spray decisions were made. To be in compliance with the law, growers must have a copy of Section 18/Emergency Use labels in their possession when the product is applied.

Integrated Pest Management

The use of Integrated Pest Management (IPM) concepts with soybean rust may be significantly different than what we have come to accept with insect or weed pests. While insecticides and herbicides can offer good rescue treatments, fungicides offer best performance when applied pre-infection or very early in the infection cycle. IPM practices for soybean rust will focus on the prediction of threat to the crop in a given area. Disease forecasting will rely on the use of field observations and weather patterns. The goal of these systems will be to alert growers to the potential for soybean rust in a timely enough manner to allow scheduling of fungicide applications to optimize product efficacy. Perhaps the greatest problem experienced by producers using fungicides against soybean rust worldwide has been early detection and treatment before the disease is out of control. This will also be a major challenge to North American soybean producers.

Albert Tenuta, Donald Hershman, Martin Draper, and Anne Dorrance
Ontario Ministry of Agriculture, University of Kentucky, South Dakota State University, and The Ohio State University

Various fungicides are available, either through Section 3 or Section 18 labels, to manage soybean rust in the United States or under an Emergency Use Registration in Canada. Each product is unique in regards to plant uptake, redistribution of active ingredient on or in host tissue, mode of action, efficacy, length of residual activity, phytotoxicity, and resistance potential. The specific characteristics of each fungicide determine how that product is used in a soybean rust management program.

Soybean rust fungicides are classified as protective or curative, depending on where in the fungal infection/disease cycle fungicidal activity is evident. (Figure 10).

Protectant fungicides

Protectant fungicides prevent fungi from successfully infecting and/or penetrating host tissue. Of the available soybean rust fungicides, chlorothalonil is an example of a product that is only active against spore germination. If this fungicide is applied after spores have germinated and the fungus has grown into (infected) the plant tissue, it will be totally ineffective in controlling the disease. The strobilurin class of fungicides (azoxystrobin, pyraclostrobin, trifloxystrobin, etc.) stops both spore germination and host penetration, but has little or no effect once the fungus has successfully penetrated or colonized host plant tissue.

Curative fungicides

Curative fungicides have the ability to inhibit or stop the development of infections that are already established. With some fungicides, this includes a degree of anti-sporulant activity which helps to slow disease development by limiting the reproductive potential of the fungus. Of the available soybean rust fungicides, only triazoles (myclobutanil, propiconazole, tebuconazole, tetraconazole, etc.) have curative activity. It is this "post-infection activity" that makes triazoles the fungicide of choice if soybean rust is established at low levels in a field. If either chlorothalonil or one of the strobilurin fungicides are applied post-infection, existing infections will continue to develop.

It is very important to remember that triazoles **do not have unlimited curative activity**. As can be seen in Figure 11 (p. 24), triazole-based fungicides have reduced once infections begin to produce spores. This is the main reason why fungicides are of little use once soybean rust has become even moderately established in a field.

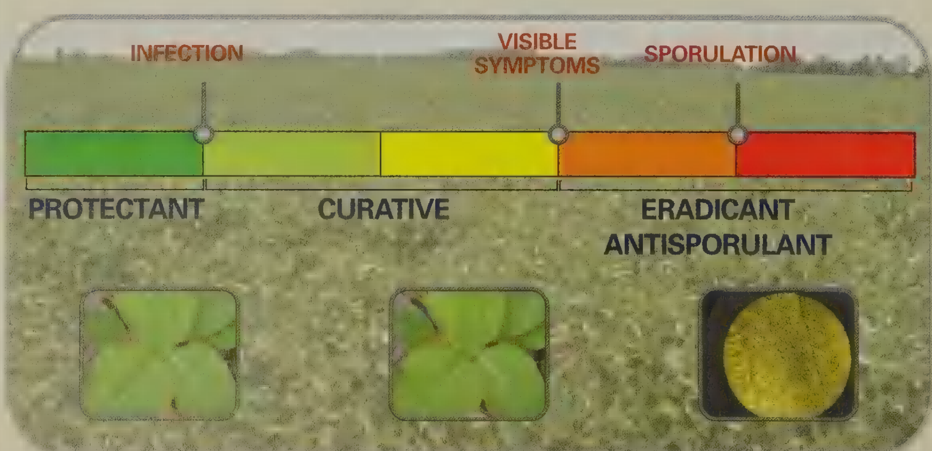


Figure 10. Schematic representation of fungicide activity in relation to Asian soybean rust development.

Combination products or on-farm mixing of fungicides

There are a few soybean rust fungicides that are marketed as a premix or co-pack of a strobilurin plus a triazole. Examples are Quilt (azoxystrobin + propiconazole; Syngenta Crop Protection), and Stratego (triflozystrobin + propiconazole; Bayer CropSciences), and HeadlineSBR (pyraclostrobin + tebuconazole; BASF). In addition, the label for Headline (pyraclostrobin, a strobilurin [BASF]) specifically recommends that a non-strobilurin, curative mixing partner be applied with Headline if soybean rust exists at any level. Both premixes and label-sanctioned tank mixes of a strobilurin + triazole are effective against spore germination, host penetration, and tissue colonization.

Check with fungicide manufacturers for compatibility before on-farm mixing of fungicides, insecticides, or herbicides.

Uptake and movement in plants

Use directions indicated on fungicide labels reflect, and are based on, unique uptake and movement characteristics for each fungicide. The main point to remember in all of this is that different fungicides, even those in the same chemical class, are not necessarily equal when it comes to uptake by plants and movement in plants. Some fungicides, such as chlorothalonil, remain on the leaf surface and are not taken up by the plant. These non-systemic, protective fungicides are present on the leaves treated and are not present on the new growth that emerges after application. Systemic fungicides, such as the strobilurins and triazoles (and premixes of the two), are taken up by plants and redistributed in tissues to varying degrees. Systemic movement is always upward and outward, and occurs in the water transport system (xylem) of plants. As a group, triazoles tend to be absorbed and redistributed more quickly and to a greater extent than the strobilurins. There are also differences in uptake and systemic movement for some fungicides in the same fungicide class. For example, pyraclostrobin is a locally-systemic strobilurin that is taken up by the plant, but does not move far beyond the point of uptake. In contrast, the strobilurin azoxystrobin is taken up by the plant and is also systemic to a limited extent beyond the point of uptake. Systemicity is not necessarily related to efficacy. Products differ in uptake and movement in that label rates and instructions reflect these differences.

Although most fungicides currently labeled for soybean rust are either systemic or locally-systemic within plants, none are as highly systemic as some commonly used insecticides and herbicides. This is another reason why coverage and canopy penetration are so important when it comes to managing soybean rust using fungicides. In addition, fungicides vary as to how quickly, and to what extent, they are taken up by the plant. This is one reason fungicide manufacturers often recommend the use of adjuvants with certain fungicides.

It is important to recognize that despite the limited systemic nature of most soybean rust fungicides, it is very important not to exceed the recommended interval between applications. Towards the end of the application interval, fungicide active ingredient is sufficiently diluted, bound up, or degraded that new growth that emerges towards the end of the interval will be mostly or completely unprotected.

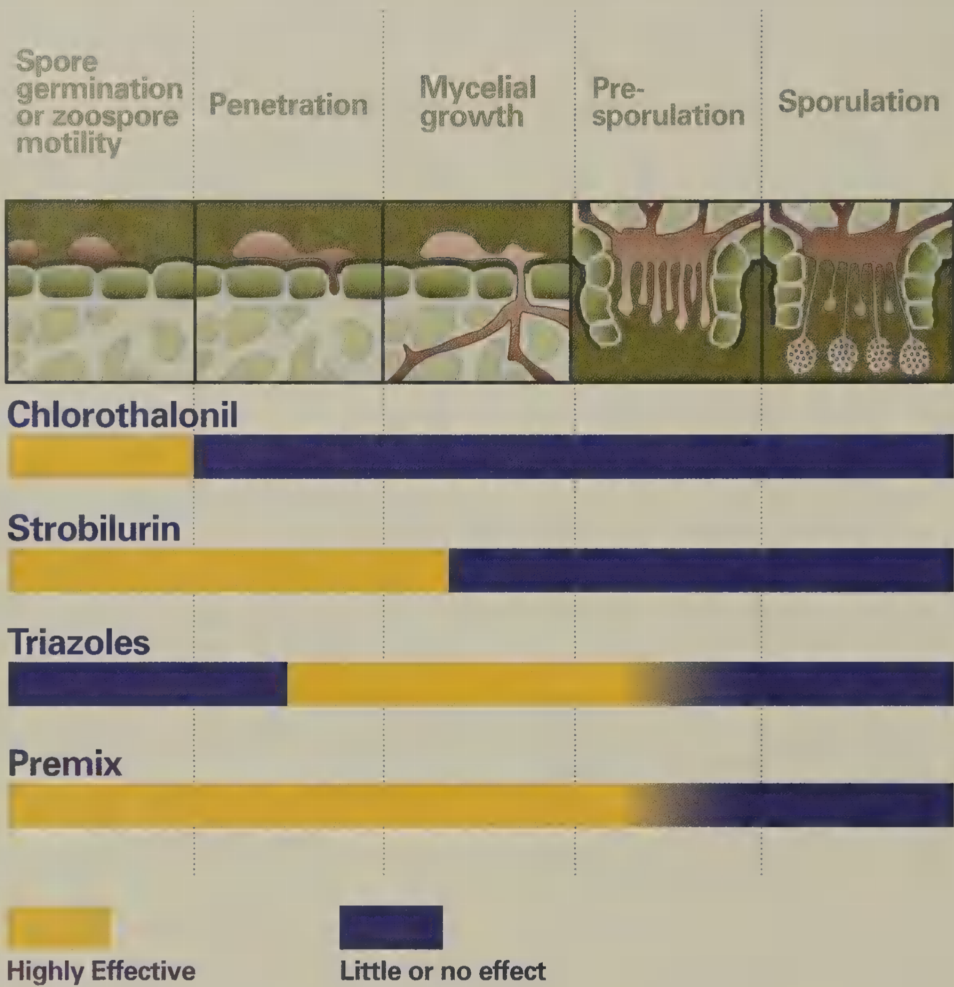
Fungicide mode of action

Fungicides available for soybean rust management have diverse modes of action:

Chlorothalonil attacks fungal cells at several sites, thereby inhibiting sulfur-containing enzymes and disrupting fungal energy production. Chlorothalonil is considered to be a "broad spectrum" fungicide because it is efficacious against a range of fungal pathogens, including *P. pachyrhizi*.

Strobilurins are broad spectrum fungicides that inhibit fungal cell respiration, thereby preventing energy production which leads to cell death. Strobilurins are referred to as "QoI" or Group II fungicides, which is simply a reference to their unique mode of action. Some labels specifically mention QoI fungicides. Thus, while it may not be critical to know how strobilurins work, it is important to recognize the QoI designation and be aware that all strobilurins have the same mode of action.

Figure 11. Fungicide impact on soybean rust developmental stages.



A single fungicide application may be adequate for economical disease control if initial disease outbreak occurs late in the season, or where disease development is significantly slowed by an unfavorable environment. Experience in South America suggests that a third application may be a rare occurrence.

Applying fungicides to a crop that exceeds 10% incidence of soybean rust in the lower to mid canopy may result in poor disease control.

Triazole fungicides inhibit biosynthesis of sterols, which are important structural components of fungal cell membranes. Triazoles are referred to as "DMI" or Group 3 fungicides, which is a reference to their unique mode of action. As mentioned above, it is not essential to know how triazoles work, but it is important to recognize the DMI designation and be aware that all triazoles have the same mode of action.

Fungicide resistance concerns

A major concern associated with strobilurin fungicides, and to lesser extent the triazoles, is the potential for resistance to develop among soybean rust populations exposed to these fungicides. Resistance concerns are based on the unique modes of action represented by the strobilurins and triazoles. Multi-site mode of action fungicides, such as chlorothalonil, have a very low risk of resistance development. In addition, rust fungi pose a lower risk of resistance than other fungal pathogens. Nevertheless, resistance to QoI fungicides has developed in other pathogens at many locations in the world, including North America.

Although fungicide resistance has yet to be observed in populations of the soybean rust fungus, it is important to take steps to reduce the risk of resistance to the strobilurins and, to a lesser degree, the triazoles. These fungicides are the "first line" of defense against soybean rust. Thus, it is imperative that we protect these very effective groups of fungicides. There are various ways this can be achieved, including:

(1) Alternate fungicides with another product that has a different mode of action. For example, alternate a strobilurin with a triazole. Another strobilurin has the same mode of action. Therefore, resistance to one of these products will result in resistance to the entire strobilurin chemical family (referred to as cross-resistance).

(2) Limit solo applications of strobilurins and triazole fungicides to one and two applications per season, respectively, and do not apply products below labeled rates. The number of applications allowed for each fungicide is clearly indicated on the label. ***NEVER use a solo application of the same fungicide or fungicide class in back-to-back applications, regardless of how many applications the label allows!***

(3) Use a premix product that contains both a preventative (strobilurin) AND curative (triazole) fungicide tank mixes if available.

(4) Monitor treated fields for signs of resistance development.

If soybean rust continues to develop after application, contact your chemical representative or Extension personnel. Scouting fields for soybean rust prior to fungicide application (detection) **AND** after application (assessment) is very important ***NOTE: Some disease will continue to develop in fields where the first application was made after some infections have already occurred. These situations could easily be confused with resistance development.***

Fungicide use strategies for soybean rust management

The following scenarios have been developed to assist in making fungicide use decisions for soybean rust management.

The table on the inside back cover lists the various fungicides available for soybean rust management in the United States. Be certain to read and precisely follow all pesticide label instructions and restrictions. Remember that pesticide labels are legal documents. As such, information presented on the label takes precedence over the guidelines and information presented in this document.

Scouting for early detection and assessment of disease progress to choose appropriate fungicide modes of action is critical for optimized response to treatment.

SCENARIO 1: LOW RUST RISK IN REGION/COMMUNITY—SOYBEAN RUST NOT DETECTED FOLLOWING INTENSIVE FIELD SCOUTING:

Crop at beginning flowering (R1) through full seed (R6): Rust risk is LOW based on reliable reports on observations from sentinel plots (local and distant), disease forecasting alerts, AND the disease has NOT been detected in the local soybean crop. **DO NOT SPRAY** REEVALUATE AT REGULAR INTERVALS THROUGH FULL SEED	1st Application	2nd Application	3rd Application
	DO NOT SPRAY	DO NOT SPRAY	DO NOT SPRAY

Limited data from some parts of the world indicate that fungicide applications made during the vegetative stages are occasionally beneficial. Most data, however, suggest that maximum benefit occurs when fungicides are applied between beginning flowering (R1) through full pod (R6). Efficacy data on fungicide use under North American conditions are needed to more clearly define the critical window of protection for soybean rust in the United States and Canada. Nevertheless, the best information to date suggests that applications made before R1, or after R6, may not produce an economic result.

SCENARIO 2: HIGH RUST RISK—PRIOR TO DETECTION: PREVENTATIVE TREATMENT

	1st Application	2nd Application	3rd Application
Crop at beginning flowering (R1) through full seed (R6): Rust risk is HIGH based on reliable reports on observations from sentinel plots (distant and local), disease forecasting alerts, but rust has NOT been detected in the local soybean crop.	**Chloronitrile** OR **Strobilurin**** OR **Premix** OR **Triazole**	**Premix** OR **Triazole**	**Premix****** (if no more than one other premix has been applied) OR **Triazole****** (if the 2nd application was not a triazole) ***May not be needed in most parts of North America***

SCENARIO 3: RUST DETECTED: CURATIVE TREATMENT

	1st Application	2nd Application	3rd Application***
Crop at beginning flowering (R1) through full seed (R6): Soybean rust is present at barely detectable levels (1–10% of observed leaves in lower crop canopy) in your fields or your neighbor's fields. NOTES: *Do not apply chlorothalonil if ANY active pustules are evident. ** Do not apply strobilurins if disease incidence exceeds 3%, or as indicated on the product label. *** Dependant upon State Section 18.	**Premix** OR **Strobilurin** + Triazole** (if allowed by the label) OR **Triazole**	**Premix** OR **Triazole** (if 1st application was not a triazole or if Premix not available	**Premix****** (if no more than one other premix applied) OR **Triazole****** (if 2nd application was not a triazole) ***May not be needed in most parts of North America***

*****Some states may have approval for three applications of Section 18 compounds. The primary restriction is that only one application of Domark and only three applications of any one active ingredient are allowed per season in any given field. Consult State Extension Service for more information in your state.*

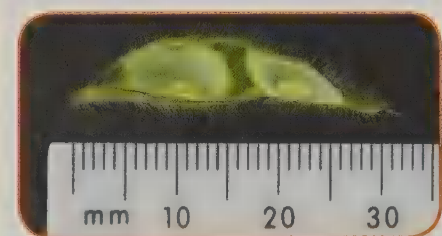
SCENARIO 4: RUST DETECTED, READILY APPARENT BY THE NAKED EYE IN THE MID-CANOPY			
Crop no earlier than beginning flowering (R1)* no later than full seed (R6); environmental conditions predicted for the next few weeks are highly favorable for rust infection.	1st Application	2nd Application	3rd Application
	Not Applicable	Not Applicable	Not Applicable

The presence of other diseases may significantly impact fungicide selection and use decisions. Consult local soybean disease guidelines where management of other foliar, pod, and stem diseases are a consideration. Furthermore, contact fungicides may perform poorly due to reduced residual.

- Spraying a fungicide when soybean rust can easily be found in the canopy of a crop may not provide satisfactory or economical disease control. Crop may not respond to treatment at this advanced stage of disease development in many environments. If treating at this stage, triazole type compounds provide the best hope of control.
- Labels for most soybean rust fungicides can only provide general guidelines on how late is "too late" because so many variables are at play, including crop stage, price, crop insurance requirements, disease severity, yield potential, etc.
- In addition, in this situation, do not apply strobilurin type compounds in order to prevent development of fungicide resistance.
- U.S. crop insurance may require treatment to meet Best Management Practices criteria for soybean. Follow those guidelines as closely as possible. Also, communicate your specific needs and situation to your ag supplier dealer; they will be most familiar with product limitations.

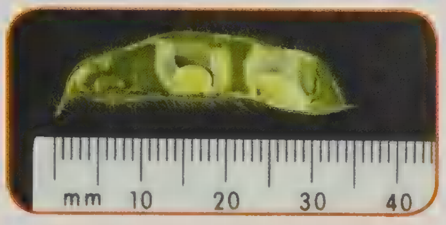
Growth Stage R3
Pod is 5 mm (3/16 inch) long at one of four uppermost nodes on the main stem with a fully developed trifoliate leaf node.

Photo used with permission from the Iowa State University publication *Soybean Growth and Development* (PM 1945)



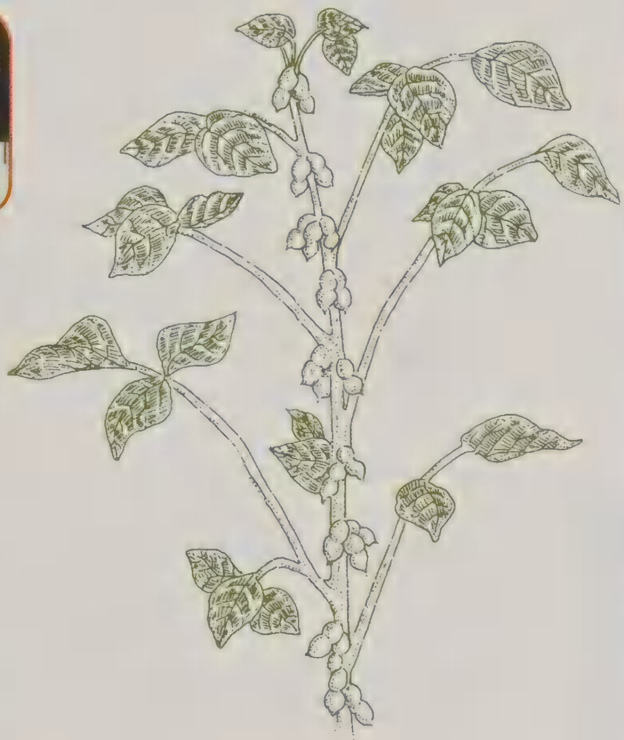
Growth Stage R4
Pod is 2 cm (3/4 inch) long at one of the four uppermost nodes on the main stem with a fully developed trifoliate leaf node.

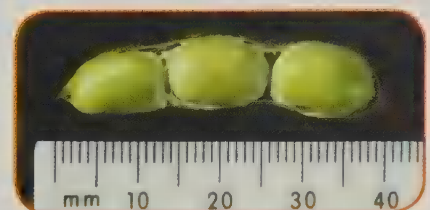
Photo used with permission from the Iowa State University publication *Soybean Growth and Development* (PM 1945)



Growth Stage R5
Seed is 3 mm (1/8 inch) long in the pod at one of the four uppermost nodes on the main stem with a fully developed trifoliate leaf node.

Photo used with permission from the Iowa State University publication *Soybean Growth and Development* (PM 1945)





Growth Stage R6
Pod containing a green seed that fills the pod cavity at one of the four uppermost nodes on the main stem with a fully developed trifoliate leaf node.

Photo used with permission from the Iowa State University publication *Soybean Growth and Development* (PM 1945)

APPLICATION BASICS — SITUATION

Erdal Ozkan, Scott Bretthauer, and Monte R. Miles
The Ohio State University and University of Illinois

Some general guidelines for successful application of fungicides for control of soybean rust are:

- Selecting the right equipment, and particularly the right type and size of nozzle for the job;
- Using appropriate spray volume and pressure;
- Applying the pesticide at the right time, and under the best possible conditions; and
- Checking the accuracy of equipment periodically to make sure that the effective dose recommended on the label is actually being applied.

The use of foliar fungicides in soybean production in the United States is a relatively new practice. Until recently, this practice has been limited to control of late-season diseases in soybean grown in the lower Mississippi River basin. Fungicides have been applied aerially at 3-5 gal per acre, or by tractor-mounted or dedicated ground spray systems with application volumes of 10-15 gal per acre. Successful control of late-season diseases has been based upon delivery of fungicides into the upper crop canopy.

Effective management of soybean rust with fungicides will depend on placing fungicides as deeply into the canopy as possible. This is because the disease usually starts in the lower canopy and moves into the middle, then upper, canopy as the crop matures. Although experience in Brazil and elsewhere suggests that existing spray technology is adequate for managing soybean rust, technology improvements are needed. However, limited research has focused on improving fungicide application in post-flowering soybean. Studies on fungicidal control of Sclerotinia stem rot, for example, have demonstrated that fungicides can be delivered into the lower canopy and provide good disease control with one application at the R3 growth stage, under moderate disease pressure. Application of fungicides to a denser canopy, later in the cropping season, may be more challenging.

Advanced spray technology is available to achieve thorough coverage of foliage when fungicides are applied. However, this may come with a higher cost. Many producers will need to modify existing spray equipment to optimize application of fungicides to full-canopy soybean. The cost of equipment modification is likely to vary widely depending on extent of modifications needed.

For example, cost may be low if only spray tips are being replaced. On the other hand, modification cost may be high if boom reconfiguration is necessary. Some producers will need to purchase new spray equipment. For many good reasons, including economic, producers tend to be conservative when it comes to extensive equipment modifications or purchasing new spray equipment. Soybean rust may help to shift this tendency since the alternative to making the necessary equipment modifications, or purchasing new equipment, may be heavy crop losses—a bigger economic burden to producers.

Pesticide manufacturers spend large amounts of time and money to determine the most effective and economical application rates for the fungicides they manufacture.

Spray angle	20-in. spacing	30-in. spacing
65 degrees	22 to 24 inches	33 to 36 inches
73 degrees	20 to 22 inches	29 to 36 inches
80 degrees	17 to 19 inches	26 to 28 inches
110 degrees	10 to 12 inches	14 to 18 inches

Table 3. Suggested minimal spray heights for given angles.

And, of course, these products are not inexpensive. Therefore, soybean producers and custom applicators should do everything possible to make sure they are applying the amount recommended on the label. Too little fungicide will result in poor control and reduced yields, while too much wastes dollars, and increases the risk of phytotoxic effects and/or environmental pollution.

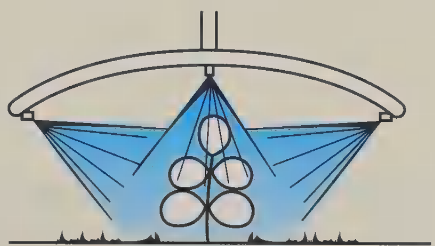
Spraying the proper amount of fungicide on each acre of soybean is not enough to achieve effective soybean rust control. Uniform deposition of fungicides on the spray target is equally important. Spray deposition, in turn, is heavily influenced by nozzle type, since each nozzle produces a unique spray pattern. For example, some nozzles require precise overlapping of patterns from adjacent nozzles to achieve uniform spray deposition.

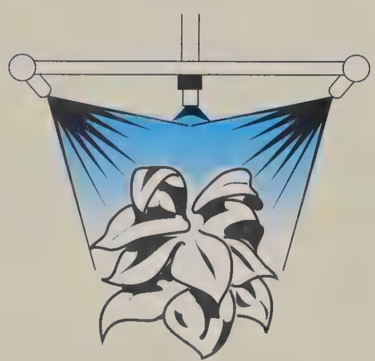
So, which spray equipment configuration is likely to provide the best defense against soybean rust? Unfortunately, we DO NOT yet have efficacy data for soybean rust using different spray equipment under U.S. conditions and limitations. However, we DO have spray coverage data from several research projects dealing with other lower canopy soybean diseases, such as Sclerotinia stem rot. An important question in these research projects has been: Does good coverage correlate with efficacy? As it turns out, in most cases there is a very strong correlation between coverage and efficacy.

How to achieve the best coverage? There are basically two ways to increase coverage: 1) reduce droplet size; and 2) increase carrier volume. Ideally, it is best to have as many small droplets hit the target as possible. Nozzles currently used in crop production tend to produce droplets that produce a large range of droplet sizes. Large droplets don't provide for good coverage because they bounce off plants and there will be fewer droplets, which reduces coverage. Very small droplets (those smaller than 100µ) lack the momentum needed to push into the canopy and most of them evaporate within a few seconds of being released from the nozzle. Thus, for soybean rust control, everything possible must be done to utilize small-to-medium size droplets, approximately 200-

To spray fungicides for soybean rust:

- Choose nozzles and adjust pressure to develop **fine** to **medium** spray quality
- Use higher spray pressure
- Flat-fan nozzles work as good as or better than cone nozzles with less drift





300µ in size. Be aware that droplets in this size range are prone to drift under windy conditions. This is an important consideration since some fungicides can significantly damage certain non-target crops.

For the above reasons, it will be necessary to use low-drift nozzles, such as flat-fan pattern, and spray pressures (60-70 psi) that will produce 200-300µ droplets in a controlled pattern.

Two additional factors that influence canopy coverage are boom height and overlap. If the application boom is too high, the distance the droplets travel before reaching the target is greater, making them more susceptible to movement by wind. Lowering the boom height reduces the risk of drift during an application. Overlap is the portion of a spray pattern that is applied over the adjoining pattern to improve uniformity. Overlap is used to prevent skips between nozzles and to even out non-uniform spray patterns. With flat-fan nozzles, the outer edges of the spray pattern have reduced volumes, but by overlapping adjacent patterns along a boom, a more uniform coverage is achieved. On a broadcast sprayer, nozzle spacing and spray height determine overlap. When the spray boom is raised, overlap increases; when the spray boom is lowered, overlap decreases. Overlap is expressed as the percentage of nozzle spacing. For example, for nozzles spaced 20 in. apart, a 50% overlap would translate into10-in. overlap (50% of 20-in.) with each neighboring nozzle. Table 3 shows recommended mounting heights for common fan angles and nozzle spacing.

Air-assisted sprayers

In spray coverage tests conducted in Ohio, air-assisted sprayers consistently provided the best coverage of paper targets placed inside the crop canopy. This advantage was even more pronounced when spray deposits were evaluated on undersides of leaves. Thus, air-assisted sprayer technology may be the best equipment option in soybean rust management programs.

Unfortunately, a commercial-scale sprayer with the air assistance may add from $10,000 to $15,000 to the price tag of the equipment. Still, this expense may be worth the investment.

If an air-assisted sprayer is not the option, then which nozzle should one should pick? First of all, if soybean is planted in a row, and there is sufficient clearance between rows at the time of spraying, some producers may opt to take advantage of directed spraying to cover the plant with more than one nozzle from different angles (from top and both sides). This can be accomplished using drop pipes between soybean rows, and attaching a double swivel nozzle to the ends of these pipes. The spray from each nozzle should then be directed toward a row of soybeans. An additional nozzle can be directed on the boom, above the row.

This method is fraught with logistical difficulties, such as nozzle/row-spacing compatibility, broken drops, and shredded canopy. Thus, drop nozzles cannot be successfully deployed in full-canopy soybean.

The nozzles we use currently produce droplets that vary greatly in size. The range of droplets from a nozzle is also affected by liquid flow rate (size of nozzle orifice), liquid pressure, and physical changes to nozzle geometry and operation. To help applicators select nozzles and use them at the most optimum droplet size range for a given situation, ASAE (American Society of Agricultural Engineers) has developed a classification system. According to this system, spray quality from a nozzle can be classified as: Very Fine, Fine, Medium, Coarse, Very Coarse, and Extremely Coarse.

Fine-to-medium spray (approximately 200-300 micron in size) is recommended by nozzle manufacturers for application of fungicides for soybean rust. To achieve this, choose the right type and size of nozzles and operate them at the appropriate pressure. Nozzle catalogs have charts to help you find out at what pressure the nozzle you picked will produce fine to medium quality spray. When drift is a concern, or you have to choose between fine and medium spray quality, choose medium.

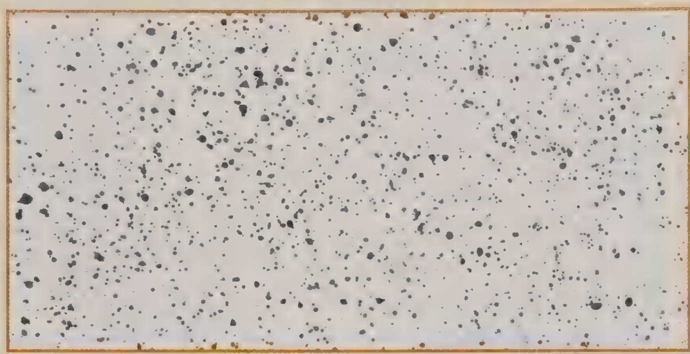
Alternately, with broadcast application select the most appropriate nozzle to achieve the desired coverage and penetration. Nozzles producing a cone pattern are not recommended for soybean rust control because they produce a higher portion of extremely small (less than 100 micron) droplets than flat-fan nozzles at any given pressure. Flat-fan pattern nozzles are generally the best choice as long as the spray from these nozzles are categorized as fine to medium.

A flat-fan nozzle set up with two spray patterns (see pictures on page 32) often provides better coverage of plants with fully developed canopies. Research has shown that hitting the target from two different angles, with one forward and one backward spray pattern, provides a more effective coverage than spraying with just one spray pattern shooting down. Several nozzle manufacturers have nozzles that provide a twin spray pattern from one tip, or special fittings/caps that allow the producers to place two nozzles in the same cap, one pointed forward, and the other one pointed backward. If the two nozzle set-up is used, the nozzles should be size 2 (0.2 gpm at 40 psi) or higher to avoid generating a high number of extremely small droplets. Choose size 4 or above when using nozzles as shown on the right.

Spray volume

Preliminary studies have shown that 10 gpa and a single fan nozzle can provide adequate canopy coverage as long as proper droplet size and pressure are used. However, as the crop continues to grow and there is more canopy to

20.0 with 2.168 GPA & VMD = 250



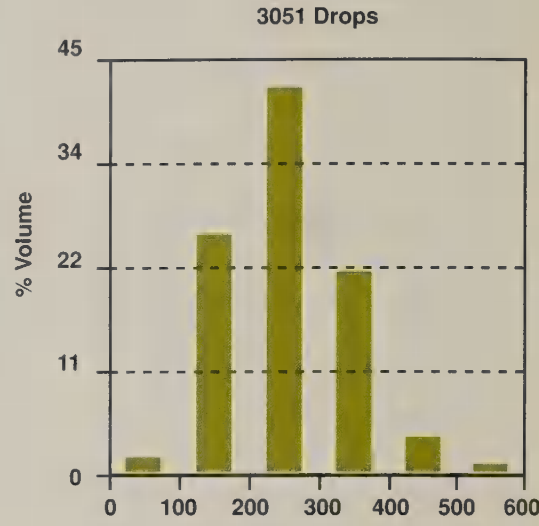
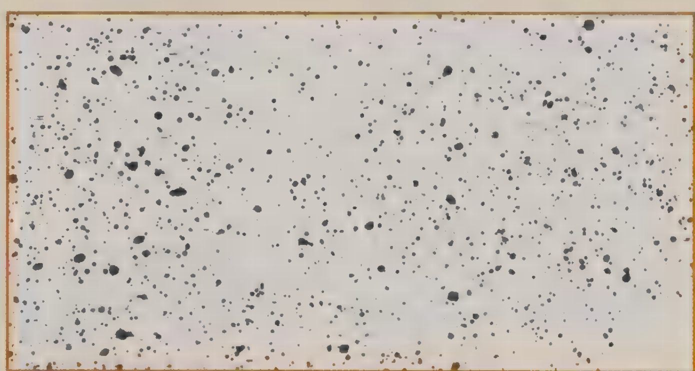


Figure 12. This indicator paper shows a volume median droplet size of 250μ. Nearly 90% of the total spray volume was delivered in droplets in the desirable size range. This pattern resulted from a ChromeCoat paper in the mid-canopy of R2 soybeans in South Dakota with 10 gpa delivered through a Turbo TeeJet (TT 110015) nozzle at 5 mph and 50 psi.

20.0 with 2.063 GPA & VMD = 255



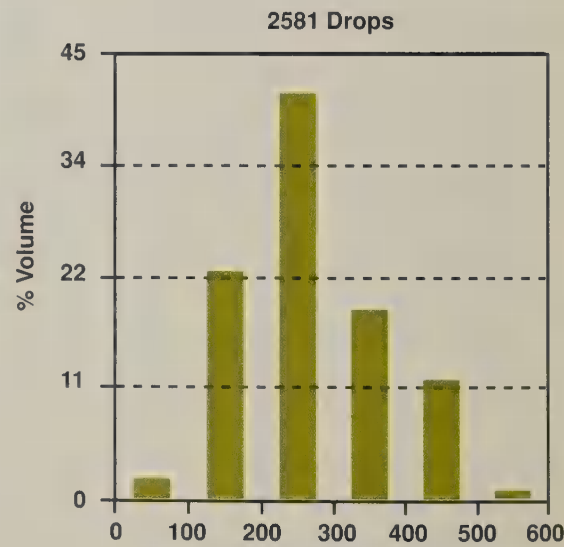


Figure 13. This indicator paper shows a volume median droplet size of 255μ. Nearly 85% of the total spray volume was delivered in droplets in the desirable size range. This pattern resulted from a ChromeCoat paper in the mid-canopy of R2 soybeans in South Dakota with 20 gpa delivered through a TwinJet (TJ60-11004) nozzle at 5 mph and 50 psi.

ASAE Standard S-572
Spray Quality Categories

category	color
Very Fine (VF)	
Fine (F)	
Medium (M)	
Coarse (C)	
Very Coarse (VC)	
Extremely Coarse (XC)	

Nozzle Size	Pressure (psi)										
	15	20	25	30	35	40	50	60	70	80	90
11001	C	M	M	M	M	M	F	F	F	F	F
110015	C	C	M	M	M	M	M	M	F	F	F
11002	C	C	C	M	M	M	M	M	M	M	F
11003	VC	VC	C	C	C	C	M	M	M	M	M
11004	XC	VC	VC	C	C	C	C	C	M	M	M
11005	XC	VC	VC	VC	VC	C	C	C	C	M	M
11006	XC	XC	VC	VC	VC	C	C	C	C	C	M
11008	XC	XC	VC	VC	VC	VC	C	C	C	C	M

cover, higher spray volumes will be needed. This is illustrated by the two cards on page 34. These cards, which were placed in the mid-canopy during application, registered a similar total deposition. The spray pattern shown in Figure 12 resulted from 10 gpa applied with a single Turbo TeeJet nozzle, while soybean was in the R2 stage. Achieving a similar deposition pattern at the R5 growth stage (Figure 13) required 20 gpa and a TwinJet nozzle. Note that the similar patterns at the two spray volumes resulted from two different nozzle types. Both nozzles, however, produced a similar range of droplet distribution, focused around the optimal 200-300μ droplet size.

In summary, coverage is critical for effective soybean rust control using fungicides. Spray volumes as low as 10 gpa may give acceptable results early in the season, but higher spray volumes will be required as the season progresses due to increasing canopy density and volume.

Environmental conditions during application

Environmental conditions during fungicide application can have a significant influence on the final spray outcome. Applications made when temperatures exceed 90°F and/or when humidity is low (< 50%) may result in excessive evaporation of smaller droplets as they leave the nozzle. Of course, spraying during windy conditions should be avoided due to drift concerns. Finally, foliage should be dry at the time fungicides are applied. Moisture on foliage (dew or rain) could reduce product efficacy due to dilution or runoff.

Serious limitations in individual and system-wide spray capacities may make it necessary to spray some fields during less than ideal conditions. Nonetheless, best control of soybean rust is likely to be achieved when fungicide applications are made as close to ideal conditions as possible.

Summary

- Choose the appropriate size and type of nozzles and operate them at a pressure that will allow them to produce small to medium (200-300μ) size droplets.
- To improve coverage in drilled soybean, consider using directed spraying.
- Use twin nozzle technology; two nozzles angled forward and backward work better than single nozzles spraying down.
- Air-assisted spray systems often provides the best coverage and droplet penetration into full-canopy soybean.
- Keep spray volumes (application rate) at minimum of 15 gpa for ground application and 5 gpa for aerial application, especially late in the growing season.
- Environmental conditions at the time of spraying can have a great influence on final disease control outcome.

AERIAL APPLICATION TIPS FOR RUST CONTROL

Dennis R. Gardisser
University of Arkansas

Any spray platform should be able to make efficient and efficacious applications for rust control. Aerial application platforms (helicopters and fixed wing) are well suited because of their speed—for timely applications, ability to work under wet field conditions, and do not compact the soil or disturb the crop. The following is a set of guidelines that should make aerial applications most productive.

All applications must be made uniformly over the entire crop.

- Make sure the aircraft is utilizing the optimum swath width.
- Avoid misses around obstructions.
- Dress headlands to get those areas around trees and power lines.
- Do not plant areas that cannot be effectively treated by aircraft. Work with your applicator to determine where these areas are—plow them up if necessary to avoid hot spots.

Utilize the optimum application height.

- Most turbine aircraft need to be operated with the spray boom 10–12 feet above the crop canopy—and the very large (660–800 gallon capacity) aircraft even higher.
- Both lower and higher release heights may reduce pattern uniformity and increase drift potential.

Don't spray during the heat of the day if possible.

As the more and more energy is absorbed into the canopy, it becomes more difficult to pass the smaller droplets through the strong micro-inversion layer that forms at the top of the crop.

Utilize nozzles that control droplet spectrums well.

Choose nozzles that make as few droplets as possible below 200µ (microns).

Years of work in heavy canopies indicate the droplet spectrums should be targeted in the 300 to 400 VMD (volumetric median diameter where ½ of the spray volume is that size or larger and ½ of the spray volume is that size or smaller) range.

- Droplet spectrum may be the most important aspect of these applications and should be carefully adjusted with nozzle selection, operating pressure, and mounting configuration.
- Small changes in droplet diameter make big changes in droplet volume. (Example: It takes (1.6) 300µ droplets to equal (1) 350µ droplet and (2.4) 300µ droplets to equal (1) 400µ.)
- There are excellent aerial models available to help determine the expected droplet spectrum. http://apmru.usda.gov/downloads/downloads.htm

Aircraft speed changes the droplet spectrum.

- The optimum droplet spectrum can generally be developed by selecting the appropriate setup configuration.
- Turbine powered, faster aircraft, generally have more uniform patterns.
- It may be more difficult for faster aircraft to work around some obstructions.

Total spray volume per acre will be somewhat dependent on crop canopy structure. The optimum GPA is in the 5–7 range.

There is generally a lot of disagreement on this issue, with a lot of opinions leaning toward more water. Canopy penetration and deposition studies just haven't indicated a strong need for more diluent volume.

The use of adjuvants and surfactants may be very beneficial as spreaders and stickers. Care should be taken to avoid major droplet spectrum changes when these products are being utilized.

If multiple applications are made, utilize different travel lanes or go in the opposite direction to move droplets into the canopy at different angles.

USING SKIP ROWS TO FACILITATE LATE-SEASON PESTICIDE APPLICATIONS

Jim Beuerlein
The Ohio State University

Sprays aimed at controlling soybean rust will typically need to be sprayed in late July or in August, well after the soybean canopy has closed. Soybean producers will need to choose between aerial and ground application, knowing that ground equipment will run down soybean rows and that an aerial application may not be available when needed.

Mid to late summer spraying with ground equipment will cause a yield loss due to soybean plants being run down. Fortunately, most commercial sprayers have narrow tires so only two rows are run down as the sprayer crosses a field with rows spaced 7.5 to 15 inches apart. The following table shows the yield loss (bu/A, $/A) when two rows are destroyed during pesticide application in mid to late summer by varying size sprayers.

Soybean growers who anticipate applying late-season pesticides to control soybean rust or other pests, such as the soybean aphid, should consider using skip-rows to facilitate pesticide application and limit yield losses associated with mechanical damage. The benefits of improving coverage and making fields more accessible for scouting far outweigh the putative yield loss. For narrow row soybeans this meets more economic criteria than 30 inch row-soybeans.

Spray boom Width (ft)	**Number of rows** covered per pass	**Percent** yield loss	**Yield loss** (bu/Acre)	**$/acre lost** at $6.50/bu
50	80	2.50	1.25	8.13
60	96	2.10	1.04	6.76
70	112	1.80	0.90	5.85
80	128	1.56	0.78	5.07
90	144	1.39	0.70	4.55

Table 4. Yield loss (bu/A, $/A) when two 7.5-inch soybean rows are destroyed during pesticide application in mid to late summer by varying size sprayers.

Bacterial Blight

- Affects mid-to-upper leaves.
- Angular lesions, reddish-brown to black centers.
- Initial angular water soaked lesions with yellow halo.

Difference from Soybean Rust: Water soaking; angular lesions; lesions on leaf underside are not raised.

Bacterial Pustule

- Affects mid-to-upper leaves.
- Lesions—small spots to large irregular shapes without water soaking.
- Lesions associate with main veins; pustules form in lesion centers on leaf underside. (10X)

Difference from Soybean Rust: Pustules not always with each lesion; pustules do not have spores in openings; openings are cracks instead of circular pores.

Downy Mildew

- Affects upper leaves.
- Spots on surface enlarge into yellow lesions.
- Older lesions turn brown with yellow-green margins; size varies with age of leaf affected.
- Fuzzy fungal gray tufts on leaf underside (20X).

Difference from Soybean Rust: Lesions larger than rust lesions; no raised pustules on underside; fuzzy fungal growth on underside.

Cercospora Blight

- Blight affects upper leaves exposed to sun after seed set; Frogeye affects lower leaves first.
- Blight starts as light purple areas on upper leaf surface which expands to cover surface; leaves leathery and dark reddish purple on upper surface only.

Difference from Soybean Rust: Blight—overall leaf area is discolored on upper surface only.

Brown Spot

- Affects lower leaves first.
- Irregular-shaped dark brown lesions on both leaf surfaces; size—small spots to large areas; adjacent lesions can form irregular shaped blotches.
- Infected leaves quickly yellow and drop.

Difference from Soybean Rust: No raised areas (on leaf) underside; angular lesions; if dark lesions, lack of uredia is key symptom; first symptoms can look like rust; has same canopy distribution as rust.

Frogeye Leaf Spot

- Frogeye lesions start as dark, water-soaked spots; can have light centers; circular to angular brown spots with dark red-brown margins.

Difference from Soybean Rust: Frogeye—discrete lesions larger than rust with defined lesion margins; no pustules evident on underside.

Pesticide labels

A pesticide label is a legal document. Each user is required by law to apply any pesticide only in a manner that is consistent with label directions. If for any reason use rates or application guidelines presented in this publication or other references are not consistent with instructions on the label, users are reminded that the label takes precedence and must be obeyed. It is ILLEGAL to apply pesticides (1) using less water than the label instructs; (increasing the concentration); (2) at a higher rate per acre than the label instructs; or (3) more frequently than the label instructs. Specified preharvest intervals (minimum number of days between the last application and crop harvest) also must be obeyed.

Pesticide formulations and spray adjuvants

Pesticide products contain at least one active ingredient that is combined with liquid or solid carriers to produce formulations that are safer or more practical to apply than the active ingredient alone. Common formulations include wettable powders, liquid concentrates, emulsifiable concentrates, dry flowable formulations, flowable liquids, soluble powders, dusts, and granules.

Several types of additives are available to improve the effectiveness of spray applications. Collectively, they are known as adjuvants. Do not use an adjuvant with any pesticide without first consulting the specific pesticide label. Improper selection or use can result in crop injury or reduced effectiveness, particularly when adjuvants are mixed with emulsible concentrates.

GLOSSARY OF TERMS

Anti-sporulant: A fungicide that reduces the rate or level of fungal spore development.

Curative fungicide: A fungicide capable of arresting the growth of an existing fungal infection in plants.

DMI: De-Methylation Inhibitors are a group of the Sterol Biosynthesis Inhibitor or Group 3 fungicides. DMI fungicides are Sterol Biosynthesis Inhibitors (SBIs) but show no cross resistance to other SBI classes. See Group 3.

Dry Flowable (DF): Formulations are similar to wettable powders, but the powders (clay particles) are formed into tiny spheres. They do not readily cake together, so they "flow" easily from the product container. Another name for this type of formulation is Water Dispersible Granule (WDG, WG).

Dusts (D): Are usually made by mixing a chemical toxicant with finely ground talc, clay, or dried plant materials.

Emulsifiable concentrates (EC): Contains a pesticide and an emulsifying agent in a solvent. ECs form suspensions when they are diluted with water for application as sprays. They leave much less visible residue than WP formulations, but are more likely to injure fruit and foliage.

Eradicative fungicide: A fungicide capable of arresting the growth of an existing fungal infection during the later stages of plant colonization, but before sporulation. Eradicant fungicides may be anti-sporulants.

Field severity: The total amount of disease in a given field. Field severity is the product of Incidence X Severity.

Flowable (F): Formulations are a liquid or viscous concentrate of suspended pesticide in water. They usually cause less injury to fruit and foliage than EC formulations and generally, but not always, are as safe as WP formulations.

FRAC: The Fungicide Resistance Action Committee is a group formed across industry to assess the risk of plant pathogens developing resistance to various classes of fungicides. FRAC is a Specialist Technical Group of CropLife International, a consortium from across the plant science industry. The purpose of FRAC is to provide fungicide resistance management guidelines to prolong the effectiveness of "at risk" fungicides and to limit crop losses should resistance occur. FRAC works to identify existing and potential resistance problems; collate information and distribute it to those involved with fungicide research, distribution, registration, and use; provide guidelines and advice on the use of fungicides to reduce the risk of resistance developing, and to manage it should it occur; recommend procedures for use in fungicide resistance studies, and; stimulate open liaison and collaboration with universities, government agencies, advisors, extension workers, distributors, and farmers.

Granules (G): Are formed by saturating an inert material such as sand or clay with a pesticide. Particles (granules) range in size from 30 to 60 mesh. Granules are applied as dry material, usually to soil or water.

Group 3: FRAC Group 3 fungicides are active against the production of sterols, especially ergosterol, a key component in the formation of fungal membranes. Fungicides in this class have activity against varying ranges of fungi, but when resistance develops, cross-resistance is the norm. Group 3 fungicides are a medium resistance risk. This group includes the triazole fungicides as well as other fungicide chemistries.

Group 11: Refers to the FRAC Group 11 fungicides with a mode of action that inhibits the outside binding site for Quinone at cytochrome bc in the Electron transport system. As such, QoI fungicides interfere with energy transfer in the fungus. Resistance has been identified in several fungal species, typically as a qualitative resistance. A fungal strain with resistance to one QoI fungicide will display cross resistance to other QoI fungicides. Group 11 fungicides are a high resistance risk. This group includes the strobilurin fungicides as well as some non-strobilurin QoI chemistries.

Incidence: The percentage of infected (at any level) plants in a field.

Infection: Penetration and colonization of the host by a pathogen.

Liquid concentrates (L or LC): Formulations containing toxicants that are water soluble. No emulsifying agents or organic solvents are required. Note—the designations L and LC are sometimes used by formulators on emulsifiable concentrates that are not water soluble.

Locally systemic: Describes a fungicide that moves relatively short distances in a plant following application and subsequent movement into plant tissue.

Mode of action: The specific mechanism by which a fungicide acts against a target fungus. The physiological processes of the fungus that are inhibited by the fungicide.

Preventative treatment: Treatment applied before infection occurs.

Protectant fungicide: A fungicide that forms a barrier to infection and prevents spore germination and/or penetration of the plant surface by the fungus.

QoI: See Group 11.

Residue: The amount of fungicide left in or on the plant. Efficacy, persistence, and tolerances are all determined by the residual activity of a fungicide.

SBI: See Group 3.

Sentinel plot: A small observation area in a crop field that is intensively sampled for the presence of a disease.

Severity: The degree of infection on a given plant. Usually represented as a percentage of the plant area diseased.

Sign: Visible fungal structures, such as a pustule.

Soluble powders (SP): Powder formulations that dissolve in water. A few pesticides and many fertilizers are prepared as soluble powders.

Strobilurin: A fungicide class that was originally derived from a compound called strobilurin A from the fungus Strobiluris tenacellus. All of the synthetic fungicides in this class are active at the same site of activity in the fungus, interrupting energy transfer in the mitochondria.

Symptom: The host's response to the infection by a pathogen, such as leaf chlorosis or lesion with necrosis.

Systemic: A product that when applied to the outside of the plant is absorbed and moved within the plant. Most products move only with the water stream (xylem), essentially from the base to the tip of the leaf.

Translaminar: Diffusion of the fungicide through the leaf from one leaf surface to the other.

Triazole: A large class of synthetic fungicides that are active at a single site in the fungus, inhibiting the production of sterols in the fungus. Sterols are important in cell membrane formation.

Urediniospore: The wind-dispersed infectious spore of rust fungi.

Volume median diameter (VMD): Common term used to describe the droplet spectrum of a nozzle. VMD is the droplet size at which half of the total spray volume coming out of the nozzle is contained in droplets larger and half of the spray volume is contained in droplets smaller. For example, a nozzle with a VMD of 510 µm contains half of its total sprayed volume in droplets with a diameter greater than 510 µm and the other half in droplets smaller than 510 µm. Another way of describing droplet sizes produced by a nozzle is the percentage of spray volume contained in droplets smaller than a specific diameter, usually 150 µm. This method of description directly addresses droplets small enough to be at risk for drift. For instance, a nozzle may be measured to produce 2 percent of its total spray volume in droplets smaller than 150 µm in diameter, which means that only a small portion of the total volume sprayed by this nozzle is contained in droplets at risk for drift.

Wettable powders (WP): Dry formulations of pesticides that are to be mixed with water for application. The toxicant is mixed with specific powders; wetting agents are added to make the mixture blend readily with water. Wettable powders form a suspension that must be kept agitated in the spray tank. Sprays prepared from wettable powders are less likely than other sprays to cause injury to fruit or foliage.

Website – Portals for Soybean Rust Information

USDA Soybean Rust Website:
www.usda.gov/soybeanrust

National Plant Diagnostic Network:
http://npdn.ppath.cornell.edu/default.htm

Plant Diagnostic Clinics in the United States:
www.apsnet.org/directories/univ_diagnosticians.asp

Plant Health Initiative:
http://www.planthealth.info/

Plant Management Network:
http://www.plantmanagementnetwork.org/infocenter/topic/soybeanrust/

Regional IPM Centers:
http://www.ipmcenters.org/

North Central IPM Center:
http://www.ncpmc.org/index.html

Northeast IPM Center:
http://www.northeastipm.org

Southern IPM Centers:
http://www.sripmc.org/

Ohio State University Soybean Rust Website:
(updates of this publication)
http://www.oardc.ohio-state.edu/SoyRust/

Selected Articles and Related Publications

Bromfield, K. R. 1984. Soybean rust, Monograph (American Phytopathological Society), No. 11. St. Paul, MN.

Feng, P. C., T. Chiu, R. D. Sammons, and J. S. Ryerse. 2003. Droplet size affects glyphosate retention, absorption, and translocation in corn. Weed Science 51: 443–448.

Hutchins, S. H., and H. N. Pitre. 1984. Effects of soybean row spacing on spray penetration and efficacy of insecticides applied with aerial and ground equipment. Environmental Entomology 13:948–953.

Hutchins, S. H., and H. N. Pitre. 1985. Differences in penetration and efficacy of insecticide sprays applied by aerial and ground equipment to soybean. J. Entomol. Sci. 20:34–41.

Kuchler, F., M. Duffy, R. D. Shurm, and W. M. Dowler. 1984. Potential economic consequences of the entry of an exotic fungal pest: The case of soybean rust. Phytopathology 74: 916–920.

Livingston, M., R. Johansson, S. Daberkow, M. Roberts, M. Ash, and V. Breneman. 2004. Economic and policy implications of wind-borne entry of Asian Soybean Rust. USDA Economic Research Service Outlook Report (OCS04D02). http://www.ers.usda.gov/publications/OCS/APR04/OCS04D02/.

Madden, L.V., and M. A. Wheelis. 2003. The threat of plant pathogens as weapons against U.S. crops. Annual Review of Phytopathology 41: (in press).

Miles, M. R., R. D. Frederick, and G. L. Hartman. 2003. Soybean rust: Is the U.S. soybean crop at risk? APSnet Feature, American Phytopathological Society. Available at: www.apsnet.org.

Mueller, D. S., A. E. Dorrance, R. Derksen, E. Ozkan, C. R. Grau, J. M. Gaska, J. E. Kurle, G. L. Hartman, C. A. Bradley, and W. L. Pedersen. 2002. Efficacy of fungicides on Sclerotinia sclerotiorum and their potential control of Sclerotinia stem rot on soybean. Plant Disease 86:26–31.

Pivonia, S., and X.B. Yang. 2004. Assessment of the potential year-round establishment of soybean rust throughout the world. Plant Dis. 88:523-529.

Sumner, H. R., G. A. Herzog, P. E. Sumner, M. Bader, and B. G. Mullinix. 2000. Chemical application equipment for improved deposition in cotton. Journal of Cotton Science 4:19–27.

Yang, X. B., A. T. Tschanz, W. M. Dlowler, and T. C. Wang. 1991. Development of yield loss models in relation to reduction of components of soybean infected with Phakopsora pachyrhizi. Phytopathology 81:1420–1426.

Zhu, H., J. W. Dorner, D. L. Rowland, R. C. Derksen, and H. E. Ozkan. 2004. Spray penetration into peanut canopies with hydraulic nozzle tips. Biosystems Engineering 87:275–283.

Zhu, H., D. L. Reichard, R. D. Fox, R. D. Brazee, and H. E. Ozkan. 1994. Simulation of drift of discrete sizes of water droplets from field sprayers. Transactions of the ASAE 37(5): 1401–1407.

Zhu, H., D. L. Rowland, J. W. Dorner, R. C. Derksen, and R. B. Sorensen. 2002. Influence of plant structure, orifice size, and nozzle inclination on spray penetration into peanut canopy. Transactions of the ASAE 45(5):

Table A.1. Conversion Factors for Weights and Measures: Proportions

Proportions	
Metric	**U.S.**
100 g/ha	1.4 oz/acre
1 kg/ha	0.9 lb/acre
1 ton(metric)/ha	0.446 tons (US)/acre
1 l/ha	0.4 qt/acre
1 kg/1000 l	1 lb/100 gal
g/1000 kg	1 ppm
1 km/hr	0.6 mph
U.S.	**Metric**
1 oz/acre	70g/ha
1 lb/acre	1.12 kg/ha
1 ton (US)/acre	2.24 tons (metric)/ha
1 fl. oz/acre	73 ml/ha
1 gal/acre	9.39 l/ha
1 lb/100 gal	1 kg/1000 l
1 ppm	1 g/1000 kg
1 mph	1.6 km/hr

To convert Celsius to Fahrenheit—multiply by 9/5 (1.8), then add 32.

To convert Fahrenheit to Celsius—subtract 32, then multiply by 5/9 (0.56)

Table A.2. Conversion Factors for Weights and Measures: **Temperatures**

Temperatures	
Celsius (Centigrade)	**Fahrenheit**
-30	-22
-20	-4
-10	14
0	32
10	50
20	68
30	86
40	104
Fahrenheit	**Celsius (Centigrade)**
0	-18
10	-12
20	-7
30	-1
40	4
50	10
60	16
70	21
80	27
90	32

Table A.3. Conversion Factors for Weights and Measures: Equivalents

	Common Equivalents	
	Metric	**U.S.**
Length	1 Millimeter	0.039 in.
	1 Centimeter (10 mm)	0.39 in.
	1 Meter (100 cm)	39.4 in.
	1 Kilometer (1,000 m)	0.62 mi.
Area	1 Square Centimeter	0.155 sq. in.
	1 Square Meter	1.2 sq. yd.
	1 Hectare (10,000 sq m)	2.47 acres
	1 Sq. Kilometer (100 ha)	247 acres
Weight	1 Gram	0.035 ounces
	1 Kilogram (1,000 g)	2.2 pounds
	1 Ton (metric) (1,000 kg)	1.1 tons (US)
Volume	1 Milliliter	0.034 fluid oz.
	1 Liter (1,000 ml)	1.056 quarts
	1 Cubic Meter (1,000 l)	264.17 gal. (US)
	U.S.	**Metric**
Length	1 Inch	2.54 centimeters
	1 Foot (12 in.)	30.5 centimeters
	1 Yard (3 ft.)	0.91 meters
	1 Mile (5,280 ft.)	1.6 kilometers
Area	1 Square Inch	6.5 square centimeters
	1 Square Foot (1.44 sq. in.)	930 square centimeters
	1 Square Yard (9 sq. ft.)	0.84 square meters
	1 Acre (43,560 sq. ft.)	0.405 hectares
	1 Square Mile (640 acres)	259 hectares
Weight	1 Ounce	28.3 grams
	1 Pound (16 oz.)	0.454 kilograms
	1 Ton (US) (2,000 lb.)	0.907 tons (metric)
Volume	1 Tablespoon (3 teaspoons)	14.79 milliliters
	1 Fluid ounce (2 tablespoons)	29.6 milliliters
	1 Cup (8 fl. oz.)	0.237 liters
	1 Pint (2 cups)	0.473 liters
	1 Quart (4 cups)	0.946 liters
	1 Gallon (US) (4 qts)	3.8 liters
	1 Cubic Foot	28.3 liters

Metric Abbreviations: mm–millimeter; cm–centimeter; m–meter; km–kilometer; ha–hectare; mg–milligram; g–gram; kg–kilogram; ml–milliliter; l–liter.

Table A.4. Oral, dermal, and inhalation toxicity ratings of pesticides.[1]

Toxicity rating	Label signal words	Oral LD_{50} (mg/kg)	Dermal LD_{50} (mg/kg)	Lethal oral dose, 150-pound man
High	Danger-Poison	0-50	0-200	few drops to teaspoon
Moderate	Warning	50-500	200-2,000	1 teaspoon to 1 ounce (2 tablespoons)
Low	Caution	500-5,000	2,000-20,000	1 ounce to 1 pint, or 2 pounds
Very Low	Caution	5,000+	20,000+	1 pint or more, or 2 pounds or more

[1] Note that values in these categories indicate LETHAL (deadly) doses; much lower doses may cause severe injury or chronic health effects.

Table A.5. Soybean Pesticides—Toxicity

Product	Oral LD_{50}	Dermal LD_{50}	Bee Toxicity
Fungicides			
Bravo WeatherStik (chlorothalonil)	9000	>2000	>181 ug/bee
Bumper (propiconazole)	>2000	>5000	not available
Domark (tetraconazole)	>5000	>2000	not available
Echo 720 (chlorothalonil)	3260	>2020	not available
Folicur (tebuconazole)	3776	2011	not available
Headline (pyraclostrobin)	>500	>4000	low toxicity
Laredo EC (myclobutanil)	2800	>5000	not available
Propimax EC (propiconazole)	not determined	not determined	not available
Quadris (azoxystrobin)	>5000	>4000	>200 ug/bee
Quilt (azoxystrobin + propiconazole)			
Stratego (propiconazole + trifloxystrobin)	4757	5050	not available
Tilt (propiconazole)	1310	>5000	>25 ug/bee
Insecticides			
Asana (esfenvalerate)	458	>2000	highly toxic
Dimethoate (dimethoate)	571	>2020	highly toxic
Lorsban (chlorpyrifos)	>5000	776	highly toxic
Mustang (zeta-cypermethrin)	234	>2000	highly toxic
Warrior (lambda-cyhalothrin)	350	>2000	0.038 ug/bee

Warning: Azoxystrobin Phytotoxic to certain Apple Varieties. Field and laboratory tests have shown that azoxystrobin is extremely toxic to certain apple varieties, mainly Macintosh apples and Macintosh-derived varieties. To date, the phytotoxic symptoms include necrosis, leaf drop, and fruit drop. Incidents have been reported on both grapes and apples in the past. Specific apple varieties that have had problems include:

Akane	Discovery	McCoun	Stark Gala
Asahi	Gala	Macintosh	Starkpur Mac
Bramley	Galaxy	Molly Delicious	Summared
Courtland	Grimes Imperial	Mondial Gala	Warabi
Cox's Orange	Kent	Ontario	Worcester
Pippin	Kizashi	Queen Cox	Pearmain
Cox	Lurared	Royal Gala	
Celbarestival		Spartan	

The most practical means of describing the droplet sizes produced by a nozzle is to categorize the droplet sizes using the entire droplet size spectrum, not just the VMD or the percentage of volume in small droplets. The classification system used in the American Society of Agricultural Engineers (ASAE) standard S-572: Spray Nozzle Classification by Droplet Spectra is an example. This classification system has six categories: very fine (VF), fine (F), medium (M), coarse (C), very coarse (VC), and extra coarse (XC). Using these categories, a nozzle and operating pressure can be selected that produce a specific droplet size spectrum. The droplet size spectrum required for a job is based on the type of pesticide being applied and is often stated on the label. Table A.6 shows the six droplet spectrum categories and their VMD ranges. Keep in mind that even though a VMD range is given for each category, the classification is based on the entire droplet spectrum produced by a nozzle, not just the VMD. The VMD is given for reference.

Table A.6. ASAE droplet spectrum classification categories, symbols,and VMD range.

ASAE Standard S-572 droplet spectrum category	Symbol	VMD (µm)
Very fine	(VF)	< 150
Fine	(F)	150–250
Medium	(M)	250–350
Coarse	(C)	350–450
Very coarse	(VC)	450–550
Extremely coarse	(XC)	>550

Table A.7. Canadian Emergency Use Fungicides Available For Soybean Rust

Fungicide	Active Ingredient	Manufacturer	Status	Rate/ Acre	Chemical class
Folicur	tebuconazole	Bayer	Emergency Use Registration	292 ml/Acre	Triazole
Headline	pyraclostrobin	BASF	Emergency Use Registration	160 to 240 ml/Acre	Strobilurin
Quadris	azoxystrobin	Syngenta	Emergency Use Registration	182 ml/Acre	Strobilurin
Tilt	propiconazole	Syngenta	Emergency Use Registration	200 ml/Acre	Triazole

Fungicide	Mode of action	No of applications	Application (gpa) (minimum)	PHI (days)	Diseases controlled
Folicur	Curative & protectant, Post-infection activity, anti-sporulant activity	1-2	10-15 5 air	21	Soybean label pending
Headline	Protectant	1	10 ground 5 air	21	Soybean label pending
Quadris	Protectant, locally systemic	1	Thorough coverage & penetration	7	Soybean label pending
Tilt	Curative & protectant Post-infection activity, anti-sporulant activity	2	Thorough coverage & penetration	40	Soybean label pending

Fungicide	Active Ingredient (ai)	Manufacturer	Status	Rate/Acre	Chemical Class	Use Strategy
Bravo® WeatherStik	chlorothalonil	Syngenta Crop Protection Inc	Section 3 Label	16–36 fl oz	Chloronitrile	Protectant
Echo 720®	chlorothalonil	Sipcam Agro USA	Section 3 Label	16–40 fl oz	Chloronitrile	Protectant
Echo 90DF®	chlorothalonil	Sipcam Agro USA	Section 3 Label	16–40 fl oz	Chloronitrile	Protectant
Quadris®	azoxystrobin	Syngenta Crop Protection Inc	Section 3 Label	6.2–15.4 oz	Strobilurin	Protectant, Systemic
Headline®	pyraclostrobin	BASF Corporation	Section 3 Label	6–12 oz	Stobilurin	Protectant, Locally systemic
Tilt® 3.6EC	propiconazole	Syngenta Crop Protection Inc	Section 18 Label	4–8 fl oz	Triazole	Curative/Protectant, Systemic, Post-infection activity, Anti-sporulant activity
PropiMax™ 3.6EC	propiconazole	Dow AgroSciences	Section 18 Label	4–8 fl oz	Triazole	Curative/Protectant, Systemic, Post-infection activity, Anti-sporulant activity
Bumper® 41.8EC	propiconazole	Makhteshim-Agan	Section 18 Label	4–8 fl oz	Triazole	Curative/Protectant, Systemic, Post-infection activity, Anti-sporulant activity
Folicur® 3.6F	tebuconazole	Bayer CropScience	Section 18 Label	3–4 fl oz	Triazole	Curative/Protectant, Systemic, Post-infection activity, Anti-sporulant activity
Laredo™ 25EC	myclobutanil	Dow AgroSciences	Section 18 Label	4–8 fl oz	Triazole	Curative/Protectant, Systemic, Post-infection activity, Anti-sporulant activity
Laredo™ 25EW	myclobutanil	Dow AgroSciences	Section 18 Label	4.8–9.6 fl oz	Triazole	Curative/Protectant, Systemic, Post-infection activity, Anti-sporulant activity
Domark® 230ME	tetraconazole	Isagro USA	Section 18 Label	5–6 fl oz	Triazole	Curative/Protectant, Systemic, Post-infection activity, Anti-sporulant activity
Stratego® 2.08F	propiconazole + trifloxystrobin	Bayer CropScience	Section 18 Label	5.5–10 fl oz	Strobilurin/ triazole	Protectant, Systemic, Post-infection activity, Anti-sporulant activity
Quilt™ 1.66EC	propiconazole + azoxystrobin	Syngenta Crop Protection Inc	Section 18 Label	14–20.5 fl oz	Strobilurin/ triazole	Curative/Protectant, Systemic, Post-infection activity, Anti-sporulant activity
Headline SBR™	tebuconazole + pyraclostrobin	Bayer CropScience/ BASF Corp	Section 18 Label	7.8 fl oz	Strobilurin/ triazole	Curative/Protectant, Systemic, Post-infection activity, Anti-sporulant activity

Mode of Action	Spray Interval (days)	Application (gpa)	PHI (days) or Growth Stage	Diseases controlled
Multi-site	14	20–150 by ground 5–10 by air	42	Anthracnose, Diaporthe pod and stem blight, Frogeye leaf spot, Purple seed stain, Cercospora leaf blight, Septoria brown spot
Multi-site	14	20–150 by ground 5–10 by air	42	Anthracnose, Diaporthe pod and stem blight, Frogeye leaf spot, Purple seed stain, Cercospora leaf blight, Septoria brown spot
Multi-site	14	20–150 by ground 5–10 by air	42	Anthracnose, Diaporthe pod and stem blight, Frogeye leaf spot, Purple seed stain, Cercospora leaf blight, Septoria brown spot
QoI – Group 11 fungicide	21	Adequate coverage and canopy penetration, include crop oil 10 by air	14	Aerial blight, Alternaria leaf spot, Brown spot, Cercospora leaf blight, Frogeye leaf spot
QoI – Group 11 fungicide	7–21	Thorough coverage of foliage not less than 5 by air	21	Soybean rust
DMI/Sterol biosynthesis Group 3 fungicide	14	15 by ground 5 by air	28	Soybean rust (Section 18 label must be in the possession of the user at the time of application)
DMI/Sterol biosynthesis – Group 3 fungicide	10–14	15 by gound 5 by air	28	Soybean rust (Section 18 label must be in the possession of the user at the time of application)
DMI/Sterol biosynthesis – Group 3 fungicide	14	15 by ground 5 by air	28	Soybean rust (Section 18 label must be in the possession of the user at the time of application)
DMI/Sterol biosynthesis – Group 3 fungicide	10–21	15 by ground 5 by air	30	Soybean rust (Section 18 label must be in the possession of the user at the time of application)
DMI/Sterol biosynthesis – Group 3 fungicide	10–14	Adequate spray volume to achieve good coverage and canopy penetration 5 by air	28	Soybean rust (Section 18 label must be in the possession of the user at the time of application)
DMI/Sterol biosynthesis – Group 3 fungicide	10–14	Adequate spray volume to achieve good coverage and canopy penetration 5 by air	28	Soybean rust (Section 18 label must be in the possession of the user at the time of application)
DMI/Sterol biosynthesis – Group 3 fungicide	N/A	20–150 by ground 5–10 by air	R5	Soybean rust (Section 18 label must be in the possession of the user at the time of application)
DMI/Sterol biosynthesis – Group 3 fungicide QoI – Group 11 fungicide	10–21	10 by ground 5 by air	21	Soybean rust (Section 18 label must be in the possession of the user at the time of application)
DMI/Sterol biosynthesis – Group 3 fungicide QoI – Group 11 fungicide	14–21	10–20 by ground 5–10 by air	28	Soybean rust (Section 18 label must be in the possession of the user at the time of application)
DMI/Sterol biosynthesis – Group 3 fungicide QoI – Group 11 fungicide	10–21	Sufficient water carrier per acre, pressure and proper nozzle selection that ensure thorough coverage. 5 by air	30	Soybean rust (Section 18 label must be in the possession of the user at the time of application)

Soybean Rust Fungicides — *Section 18 labels are active until November 10, 2007*